

FOURTH QUARTERLY REPORT  
DEVELOPMENT OF HIGH-PERFORMANCE LIGHT-WEIGHT ELECTRODES  
FOR HYDROGEN OXYGEN FUEL CELLS

by

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## 1. INTRODUCTION

### 1.1 Objectives

Light-weight fuel batteries capable of producing large quantities of energy appear feasible for space applications. High-performance light-weight electrode systems are an essential part of these batteries. Work completed previously<sup>(1)</sup>, under NASA Contract NAS 3-2786, showed that American Cyanamid AB-40 electrodes (40 mg Pt/cm<sup>2</sup>) gave high and sustained performance in hydrogen-oxygen matrix fuel cells including those of battery size; this performance is substantially higher than that of American Cyanamid AB-1 electrodes which contain less platinum (9 mg Pt/cm<sup>2</sup>). It was calculated that at temperatures up to 100°C, the AB-40 electrodes could be incorporated in a 2 kw fuel battery whose weight per net power (including all auxiliaries except fuel and tankage) would be approximately 50 lb/kw.

A detailed investigation at temperatures up to 100°C showed that initial performance generally increases with increasing temperature, pressure, and electrolyte (KOH) concentration. Furthermore, preliminary studies demonstrated that substantial increases in initial performance can be obtained by operating at higher temperatures (140°C) and KOH concentrations (65%), than are generally employed in matrix fuel cells. Under these conditions current densities as high as 100, 400 and 800 ma/cm<sup>2</sup> at working voltages of 1.0, 0.9 and 0.8 v, respectively, were achieved in short-term tests.

Accordingly, the objective of the present contract is to investigate and recommend preferred conditions, at 100-200°C under which AB-40 electrodes would be capable of sustained high performance in a total module having a weight-to-power ratio substantially lower than those presently available for space environment.

## 1.2 Scope

The scope of the work to be done by American Cyanamid Company during the Contract Year is outlined in the Schedule of Work presented in the First Quarterly Report<sup>(2)</sup>.

Work in the fourth quarter of the contract was devoted to Tasks I-B, II and III. Four test stations were constructed for small cell life testing at pressures above atmospheric. Small cell life tests were conducted at temperatures up to 125°C and pressures up to 45 psig (Task I-B). Three battery-size cells and three test stations were constructed for large cell life testing at pressures above atmospheric (Task II). Large cell life tests were conducted at 100°C at pressures up to 45 psig (Task III).

## 2. SUMMARY

### Task I-B

1. Atmospheric pressure life tests were conducted in 2-inch cells (2 inch square electrodes) at 100-125°C, 50-60% KOH and 100-300 ma/cm<sup>2</sup>. Asbestos matrices were employed at 100°C. A proprietary ceria-PTFE matrix was employed at 100-125°C. The inlet gases were either dry or humidified.

2. At 100°C and 100 ma/cm<sup>2</sup> two tests which had previously passed contract specifications for stable operation, continued to run stably for an additional 2200 hours to a total test time of 3690 hours. The voltage levels in these tests were 0.86-0.93 v (ACCO-I Asbestos matrix) and 0.90-0.93 v (Fuel Cell Asbestos matrix).

3. Four additional tests, at 100°C and 100 ma/cm<sup>2</sup> have passed contract specifications. During 1200 hours, sustained voltage levels were 0.93-0.94 v with ACCO-I Asbestos, 0.94 v with Quinterra Asbestos and 0.91-0.93 v with Fuel Cell Asbestos (two tests). Voltage decline rates were 1.2, 0, and 0-2.3 mv/100 hours, respectively. These tests continue to run stably up to 1440-2150 hours at overall voltage decline rates of 0-1.8 mv/100 hours.

4. At 100°C and 200 ma/cm<sup>2</sup>, a test with Quinterra Asbestos has passed contract specifications. During 1200 hours the voltage was 0.88-0.89 v and the voltage decline rate 0.8 mv/100 hours. Fuel Cell Asbestos has not yet yielded stable operation at 200 ma/cm<sup>2</sup>.



5. At 100°C and 300 ma/cm<sup>2</sup>, two more tests with ACCO-I Asbestos passed contract specifications. During 1200 hours the voltage levels were 0.84-0.88 v and the voltage decline rates 1.7-3.5 mv/100 hours. These tests are still running stably after 1600 hours.

A test with ACCO-I Asbestos which had previously passed contract specifications became unstable after 1200 hours.

6. At 125°C and 100 ma/cm<sup>2</sup>, a test with a ceria-PTFE matrix passed contract specifications. During 1200 hours the voltage was 0.96-0.98 v and the voltage decline rate 1.5 mv/100 hours.

A test with the ceria-PTFE matrix at 125°C and 200 ma/cm<sup>2</sup> has run stably for 325 hours at 0.93-0.94 v.

7. Previous conclusions<sup>(4)</sup> that stable operation can occur at 100-300 ma/cm<sup>2</sup> when the overall KOH concentration gradient in the cell is below 6-7% KOH were further confirmed.

8. Four stations were constructed for life testing at pressures above atmospheric. Each station was equipped to humidify both inlet gases. Automatic shutdown was provided in the event of a rise in cell temperature or a rise or fall in gas pressure.

9. Life tests at pressures above atmospheric employed matrices of Fuel Cell Asbestos, Quinterra Asbestos or ceria-PTFE. These matrices have bubble pressures of 16-30 psig. ACCO-I Asbestos was not used because of its low bubble pressure (1-3 psig).

A test at 100°C, 15 psig and 200 ma/cm<sup>2</sup> (Fuel Cell Asbestos matrix) was nearly stable. During 1200 hours, the voltage was 0.86-0.92 v with a decline rate of 5.6 mv/100 hours.

A test at 100°C, 45 psig and 200 ma/cm<sup>2</sup> (Quinterra Asbestos matrix) ran stably at 0.92-0.94 v for 580 hours.

A test at 125°C, 45 psig and 100 ma/cm<sup>2</sup> (ceria-PTFE matrix) ran stably for 300 hours at 1.03-1.04 v.

10. Four tests at 45 psig (including those described above) were terminated by a loss in hydrogen line pressure.

#### Task II

1. Three battery-size cells (6 inch square electrodes) were fabricated for large cell life testing at pressures above atmospheric.

#### Task III

1. Three stations were constructed for large cell life testing at pressures above atmospheric. Each station was equipped to humidify one inlet gas. Automatic shutdown was provided in the event of a rise in cell temperature or a rise or fall in gas pressure.

2. Large cell life tests were conducted at 100°C and 50% KOH. In all tests the removal of product water simulated that of a battery system with a recycle hydrogen stream and dead-ended oxygen. One test was run with an ACCO-I Asbestos matrix at atmospheric pressure and 300 ma/cm<sup>2</sup>. Four tests were run with either Fuel Cell Asbestos or Quinterra Asbestos at 45 psig and 100 ma/cm<sup>2</sup>. None of the tests ran stably during 118-190 hours. Voltage decline rates were 11-24 mv/100 hours.

3. Two large cell life tests were terminated by a loss in hydrogen line pressure. Attempts to re-start one of these tests resulted in an explosion in the hydrogen saturator tank which was probably caused by cross-leakage of oxygen through the cell matrix. The explosion damaged the saturator but not the cell.

4. As a result of the explosion both the large cell and the small cell pressure cell stations were re-designed. Each re-designed station is to be provided with both manual and automatic nitrogen purging and with a double pair of check valves in each reactant fuel line. In the small cell stations the saturators will have a smaller vapor space (100 cc) and will be able to withstand higher pressures than previously (at least 2000 psig). The large cell stations will run without saturators. One station will run with dry gases. The second station will run with both gases humidified in a small vaporizer.

Construction of the six re-designed pressure stations is scheduled for the first week of April through the first week of May.

### 3. SMALL CELL TESTING

Previous work<sup>(3,4)</sup> defined quantitatively the improvement in initial cell voltage which results from operation at temperatures above 100°C (125-150°C), pressures above atmospheric (15-60 psig) and KOH concentrations above 30% (40-75%). Within these ranges of the operating variables, highest initial performance at 100-400 ma/cm<sup>2</sup> occurs at 150°C, 45-60 psig and, depending on current density and temperature, at 60-75% KOH. Stable operation, (<4.2 mv/100 hours decline) at 100°C, 50% KOH and atmospheric pressure, was demonstrated previously for 1200 hours or more at 100-300 ma/cm<sup>2</sup> with ACCO-I Asbestos matrices and at 100 ma/cm<sup>2</sup> with Fuel Cell Asbestos and ACCO-II Asbestos<sup>(4)</sup>. These matrices were shown to be limited for long term operation to temperatures up to 100°C. Fuel Cell Asbestos and ACCO-II Asbestos have sufficient bubble pressure (20-30 psig) to be used at pressures above atmospheric. The low bubble pressure of ACCO-I Asbestos (1-3 psig) limits its use to atmospheric pressure operation.

During the current period, small cell life testing aimed at: (1) duplicating previous test results with ACCO-I Asbestos, (2) demonstrating stable performance at atmospheric pressure and current densities up to 200-300 ma/cm<sup>2</sup> with matrices suitable for pressure operation, (3) operating stably at 45 psig and (4) operating stably at 125°C.

Fuel Cell Asbestos and Quinterra Asbestos matrices were employed for pressure operation at 100°C. Quinterra Asbestos has the same bubble pressure as Fuel Cell Asbestos. It is less dense and less resistive and

thus is potentially more useful at high current densities. Experimental testing with ACCO-II Asbestos was discontinued since previous work<sup>(3)</sup> showed this matrix to have no substantial advantage over commercially-available Fuel Cell Asbestos. A ceria-PTFE matrix was employed at 100-125°C. This matrix is potentially useful at temperatures up to at least 150°C though not at 200°C<sup>(3)</sup>. Because of its high bubble pressures (16-20 psig) the ceria-PTFE matrix can also be used at pressures above atmospheric.

Tables 3-1 and 3-2 summarize the operating conditions and results of all small cell tests at atmospheric pressure and at pressures above atmospheric, respectively. In all tests the electrodes were pre-wet to 20% of their weight with 50% KOH. The asbestos matrices were 20-25 mils thick when dry. The ceria-PTFE matrices were 24-37 mils thick when wet with water. The specific gravities of the dry matrices are 0.81 for Fuel Cell Asbestos, 0.33 for ACCO-I Asbestos, 0.61 for Quinterra Asbestos and 2.58 for 95/5 Ceria/PTFE. On a weight basis KOH loadings in the matrix (g/g dry matrix) were 1.3-1.6 for Fuel Cell Asbestos, 3.1-3.5 for ACCO-I Asbestos, 2.9-3.2 for Quinterra Asbestos and 0.5-1.1 for ceria-PTFE. On a volume basis these same respective loadings were (0.70-0.86), (0.68-0.77), (1.18-1.30) and (0.69-1.86) cc KOH/cm<sup>3</sup> dry matrix. Hydrogen and oxygen entered the cell dry or were humidified at 45-55°C. In nearly all runs the inlet ratio of hydrogen/oxygen was 1.0. Figures 3-1 to 3-6, 3-12 and 3-13 show the changes of cell voltage and resistance with time.

### 3.1 Atmospheric Pressure Life Tests

#### 3.1.1 Tests at 100°C

Small cell tests at atmospheric pressure, 100°C and 50% KOH are discussed below in order of increasing current density.

##### 3.1.1.1 Tests at 100 ma/cm<sup>2</sup>

Figures 3-1 and 3-2 show runs at 100 ma/cm<sup>2</sup> for periods shorter than and longer than 2000 hours, respectively.

Two tests which had previously passed contract specifications for stable operation continued to run stably for an additional 2200 hours to a total test time of 3690 hours. With ACCO-I Asbestos (TLT-2-322) the voltage level was 0.86-0.93 v and the overall voltage decline rate was 1.7 mv/100 hours. With Fuel Cell Asbestos (TLT-2-324) the voltage level was 0.90-0.93 v and the overall voltage decline rate was 1.0 mv/100 hours.

Four additional tests have passed contract specifications. During 1200 hours, sustained voltage levels were 0.93-0.94 v with ACCO-I Asbestos (TLT-2-357), 0.94 v with Quinterra Asbestos (TLT-2-354) and 0.91-0.93 v with Fuel Cell Asbestos (TLT-2-358 and -2-359). Voltage decline rates were 1.2, 0 and 0-2.3 mv/100 hours, respectively. These tests continued to run stably after 1440-2153 hours at overall voltage decline rates of 0-1.8 mv/100 hours.

Another test with ACCO-I Asbestos (TLT-2-356) ran stably for 520 hours at 0.94 v and a voltage decline rate of 2.0 mv/100 hours. Cross-leakage of gas through the matrix then developed causing an accelerated voltage decline. Loss of electrolyte from the cell may have also contributed to the decline. The test was terminated at 688 hours.

Two tests were started with the ceria-PTFE matrix to check its performance at 100°C before using it at higher temperatures. The inlet gases were humidified at 55°C. One test (TLT-2-407), employing a 24 mil thick matrix, ran stably for 940 hours at a voltage decline rate of 0.6 mv/100 hours. The voltage level (0.93-0.94 v) equalled that obtained with ACCO-I Asbestos and Quinterra Asbestos and was somewhat above that obtained with Fuel Cell Asbestos (0.91-0.93 v). The second test, (TLT-2-406), employing a thicker matrix, (37 mils) also ran stably, for 331 hours, but at a higher voltage decline rate (2.6 mv/100 hours) and at a somewhat lower voltage level (0.92-0.93 v).

#### 3.1.1.2 Tests at 200 ma/cm<sup>2</sup>

Runs at 200 ma/cm<sup>2</sup> are shown in Figure 3-3. A test with Quinterra Asbestos, on dry gases (TLT-2-354) was run at 200 ma/cm<sup>2</sup> after it had first run at 100 ma/cm<sup>2</sup> for 1440 hours. The test ran at 0.88-0.89 v for 1200 hours and passed contract specifications. The voltage decline rate was 0.8 mv/100 hours.

Three tests with Fuel Cell Asbestos did not run stably. Test TLT-2-358 had first run stably at 100 ma/cm<sup>2</sup> for 1669 hours. At 200 ma/cm<sup>2</sup> the voltage decline rate was 6.0 mv/100 hours during 459 hours. Similarly, test TLT-2-359 had first run stably at 100 ma/cm<sup>2</sup> for 1707 hours. During 326 hours at 200 ma/cm<sup>2</sup> the voltage decline rate was 25 mv/100 hours. In both of these tests the inlet gases were humidified at 45°C. Test TLT-2-406 was started at 200 ma/cm<sup>2</sup> on gases humidified at

55°C. During 1434 hours the voltage decline rate was 8.7 mv/100 hours. However, no voltage loss occurred during a 510 hour period (300-810 hours elapsed time).

#### 3.1.1.3 Tests at 300 ma/cm<sup>2</sup>

Figures 3-4 and 3-5 show runs at 300 ma/cm<sup>2</sup> for periods shorter and longer than 2000 hours, respectively. All tests employed ACCO-I Asbestos as the matrix.

Test TLT-2-335 which had passed contract specifications during the second quarter continued to run stably at 0.83-0.86 v until 2100 hours. During this period the maximum voltage decline rate was 4.2 mv/100 hours (from 640-1920 hours). From 2100-3200 hours the voltage declined at an unstable rate (11 mv/100 hours) to 0.71 v accompanied by a rise in cell resistance. Gas cross-leakage caused termination of the test at 3200 hours.

Two additional tests passed contract specifications at 300 ma/cm<sup>2</sup> (TLT-2-404 and -405). TLT-2-404 ran at 0.85-0.86 v for 1200 hours with an overall voltage decline rate of 0.8 mv/100 hours, despite some gas cross-leakage which began at approximately 500 hours. From 1200-1632 hours the voltage decline rate was 7.0 mv/100 hours. The test was then terminated although the overall voltage decline rate was still only 2.0 mv/100 hours. TLT-2-405 ran for 1200 hours at 0.88-0.89 v with an overall voltage decline rate of 3.2 mv/100 hours. The test is still running stably at 1605 hours with an overall decline rate of 3.9 mv/100 hours.

Test TLT-2-403 was nearly stable. During 1200 hours the voltage decreased from 0.88 v to 0.81 v at a decline rate of 5.5 mv/100 hours. By 1726 hours the voltage declined to 0.76 v and the test was terminated.



Tests TLT-2-401 and -402 had initial voltages of 0.85 v and 0.86 v. Both had rapid voltage decline rates (32 and 20 mv/100 hours during 117 and 161 hours, respectively) and were terminated.

Test TLT-2-355 employed an ACCO-I matrix containing 20% binder instead of the usual 10%. Nearly all of the product water was removed by hydrogen humidified at 55°C. Oxygen entered the cell dry and was essentially dead-ended. During 1000 hours the test ran stably at 0.84-0.88 v. The voltage decline rate was 4.6 mv/100 hours. At 1000 hours a surge of water from the saturator drained electrolyte from the cell, decreasing the current and voltage sharply. The run was then terminated.

### 3.1.2 Tests at 125°C

Tests at 125°C were run at 60% KOH. All tests employed the 95/5 ceria-PTFE matrix. Results are shown in Figure 3-6.

Test TLT-2-360 was run at 100 ma/cm<sup>2</sup> and 125°C after the test had first run stably at 100°C for 331 hours. The test passed contract specifications. During 1200 hours the voltage level was 0.96-0.97 v and the voltage decline rate 1.3 mv/100 hours.

Test TLT-2-408 was started at 100 ma/cm<sup>2</sup>. The test ran stably at 0.96-0.99 v for 1000 hours after which the voltage declined at an accelerated rate. At 1169 hours the overall voltage decline rate was 4.0 mv/100 hours.

These tests at 125°C and 60% KOH demonstrate the improvement in sustained performance level that results from simultaneously increasing the KOH concentration and temperature. The voltage levels sustained during 1200 hours at 100 ma/cm<sup>2</sup> are 20-50 mv higher than the highest voltage

sustained at 100°C and 50% KOH with asbestos matrices [i.e., with ACCO-I Asbestos (TLT-2-322 and -354) and with Quinterra Asbestos (TLT-2-354)] and are 60-80 mv higher than the voltages sustained with Fuel Cell Asbestos (TLT-2-324, -358 and -359). It should be noted that this increase in the sustained voltage was not caused by any lower matrix resistivity: Both the resistivity and the sustained performance of the Ceria-PTFE matrix at 100°C and 50% KOH were substantially the same as that of ACCO-I Asbestos and Quinterra Asbestos (Section 3.1.1.1).

Test TLT-2-407 was run at 125°C and 200 ma/cm<sup>2</sup> after the test had first run stably at 100°C and 100 ma/cm<sup>2</sup> for 940 hours. During 320 hours the test has run stably at 0.93-0.94 v at a voltage decline rate of 2.8 mv/100 hours. This voltage level is 50 mv above the highest voltage obtained for the same duration at 100°C, 50% KOH and 200 ma/cm<sup>2</sup>, i.e. with Quinterra Asbestos (TLT-2-354).

Consequently the Ceria-PTFE matrix can operate stably at 125°C while asbestos-containing matrices cannot (3, 4). This permits an increase in KOH concentration from 50% to 60% which, at a voltage level of 0.93-0.94 v, doubles the sustained power density from 88 to 176 watts/ft<sup>2</sup>.

### 3.1.3 Cell Resistance and Voltage Stability

In the life tests described above at 100°C and 50% KOH with 20-25 mil thick matrices, the sustained cell resistance increased in the order of matrices, ACCO-I Asbestos and Quinterra Asbestos (3-4 milliohms), Ceria-PTFE (4 milliohms) and Fuel Cell Asbestos (6-7 milliohms). (The 6 milliohm resistance of a 37 mil Ceria-PTFE matrix is consistent with the resistance of the thinner Ceria-PTFE.)

During all tests at 100°C the cell resistance was constant to within  $\pm 1$  milliohm. Thus in those tests where the voltage declined substantially, the decline was not caused by a rise in cell resistance.

In one test at 125°C (TLT-2-408) the voltage decline during 720 to 1169 hours was caused at least partly by a rise in cell resistance (starting at 560 hours) from 5 milliohms to 8 milliohms.

#### 3.1.4 KOH Concentration Gradient and Voltage Stability

The overall KOH concentration gradient in the cell was determined from water collection measurements. The concentration at the oxygen electrode was nearly always greater than at the hydrogen electrode. Table 3-3 compares the concentration gradient with the voltage decline rate for all determinations made with the various matrices at 100-125°C, 50-60% KOH and 100-300 ma/cm<sup>2</sup>. In most runs the concentration data was obtained within some interval of the total test period. For these runs the voltage decline rates were computed for these intervals. In runs where concentrations were measured only once, the voltage decline rate was computed from the start of the test to the time of measurement. Thus the decline rates of Table 3-3 are not necessarily the same as the overall decline rates shown in Table 3-1.

The results shown in Table 3-3 confirm previous conclusions<sup>(4)</sup> that stable operation can occur at 100-300 ma/cm<sup>2</sup> when the overall concentration gradient is below 6-7% KOH (TLT-2-322, -335, -357, -324, -358, -359, -406, -354, -360, and -408). Higher concentration gradients (8-15%) cause unstable operation (TLT-2-401, -402, -403, and -404). This is shown

more directly in Figure 3-7 which combines the data of Table 3-2 with that reported previously<sup>(4)</sup>. Average values of the concentration gradient from each run are shown in the figure.

In test TLT-2-405 the relationship between voltage and concentration gradient was confirmed with the test itself. In the early part of the test (117 hours) the concentration gradient was 12.5% KOH and the test ran unstably at a decline rate of 25 mv/100 hours. From 543-1605 hours the concentration gradient was 3-7% KOH and the test ran stably at 2.7 mv/100 hours.

Only two exceptions to the general trend occurred. In test TLT-2-358, the voltage at 200 ma/cm<sup>2</sup> was unstable at a decline rate of 6.6 mv/100 hours even though the concentration gradient was 0.5-2.5% KOH. In test TLT-2-322, the concentration gradient unexplainedly increased from 3.5-6.0% during 1653-2921 hours to 11.5-13.5% during 3284-3451 hours. Nevertheless, the voltage remained stable.

In test TLT-2-335 the voltage was stable from 1436-1749 hours when the concentration gradient was 1.5-2.5% KOH. From 2393 to 2812 hours the gradient unexplainedly shifted direction (1.5-6.0% KOH higher on the hydrogen side) and the test became unstable.

### 3.2 Pressure Life Testing

#### 3.2.1 Pressure Test Stations

Four test stations were constructed, suitable for life testing at pressures up to 60 psig with both inlet gases humidified. A typical station is shown schematically in Figure 3-8. Each gas is passed through an Ascarite scrubber to remove trace CO<sub>2</sub> and then flows through a solenoid

valve, pressure regulator, flowmeter and saturator before entering the cell. To maintain both saturators at a uniform temperature, the saturators are placed in contact and wrapped with a common heating tape and insulation. An on-off controller with a probe inserted into the water regulates the temperature. The lines from the saturators to the cell are heated to prevent condensation. Most of the water in each gas stream leaving the cell is condensed in the coil at ambient temperature and returned to the cell. The excess water accumulating in the saturator is drained periodically. Each exit gas then flows out of the system through a needle valve which regulates its flow rate. "High" and "low" pressure Mercoid switches close both inlet gas solenoid valves if the pressure of either gas in the system rises or falls by 5 psig. Similarly a high temperature cut off probe, inserted in one face plate of the cell, closes both inlet gas solenoid valves if the cell temperature rises by  $10^{\circ}\text{C}$ . The resulting drop in system pressure trips the low pressure Mercoid. This prevents the solenoids from re-opening once the cell temperature drops below the cut-off temperature.

Two square test cells and two round test cells were used. Figures 3-9 and 3-10 show their designs. The square cells were built and tested first. The face plates are  $3/8$  inches thick and are made of nickel. The electrodes and spacer screens are contained in a chamber formed by the face plate cavities. The cavity in each face plate is  $2\frac{1}{4}$  inches square x 0.10 inch deep. Gas distribution within the electrode cavity (not shown) is the same as in the small atmospheric pressure cell. One flat spacer screen (16 mesh and  $2\frac{1}{4}$  mils thick) is adjacent to each electrode while

one corrugated spacer screen (40 mesh and 20 mils thick) is adjacent to each face plate. The spacer screens are of nickel, plated with 0.05 mil of high temperature gold. They are placed so that after assembly the top surface of each electrode is flush with the top surface of the cavity. The matrix extends over four lands and three grooves surrounding the electrode cavity to the edge of the square "O" ring. Sealing is accomplished by compression of the matrix between the lands. The grooves permit electrolyte to be squeezed out during cell assembly, thus preventing hydraulic rupture of the matrix. Leakage of gas or electrolyte out of the cell is provided by the butyl rubber "O" ring. A sheet of 5 mil PTFE outside the "O" ring insulates the face plates electrically. The cell is heated externally by thin heating elements regulated by an on-off controller.

The round cells (Figure 3-10) have circular grooves and were designed after the machining of square grooves proved to be difficult. Otherwise their basic design is the same as that of the square cells.

Figure 3-11 shows the saturator design. The saturator body is of copper. The porous sparger is made of stainless steel. At the maximum flow rates anticipated for operation at 200 ma/cm<sup>2</sup> (1000 cc/min) the pressure drop through the sparger is less than 1 psig. Preliminary testing showed that the liquid depth (5 inches) is sufficient to saturate the gases at flow rates up to the maximum. Condensate returns to the saturator below the liquid surface in order to prevent mixing of the inlet and exit gas. Water accumulating in the saturator is drained out of the side port.

### 3.2.2 Pressure Test Results

All small cell pressure tests started during the Fourth Quarter were run at 45 psig with both inlet gases humidified at 55°C. Test TLT-2-340, started during the Third Quarter, was run at 15 psig on dry gases.

Tests at 100°C and 50% KOH are shown in Figure 3-12.

Test TLT-2-340 was run in a square cell with a Fuel Cell Asbestos matrix at 100°C, 50% KOH and 200 ma/cm<sup>2</sup>. During 1200 hours the voltage was (0.86-0.92 v). The decline rate (5.6 mv/100 hours) was somewhat above that considered stable (4.2 mv/100 hours). The test was terminated at 1440 hours in order to build the four test stations described in Section 3.4.1.

Test TLT-2-412 was run in a round cell with Fuel Cell Asbestos at 100 ma/cm<sup>2</sup>. The initial voltage was 0.987 v. During 72 hours the voltage decline rate (70 mv/100 hours) was very high.

Test TLT-2-413 was started in a square cell with Fuel Cell Asbestos at 200 ma/cm<sup>2</sup>. The initial voltage was 0.961 v. During 49 hours the voltage decline rate (150 mv/100 hours) was very high.

A test with Quinterra Asbestos (TLT-2-409) was run in a square cell at 200 ma/cm<sup>2</sup>. The initial voltage (0.959 v) fell to 0.936 during the first two hours. The test then ran stably for 580 hours at an overall voltage decline rate of 3.5 mv/100 hours. The voltage was mostly 0.92-0.94 v. Thus, operation at 45 psig doubles the sustained power density at 0.92-0.94 v (from 88 to 176 watts/ft<sup>2</sup>) compared with that obtained at atmospheric pressure under otherwise identical conditions, (Test TLT-2-354 in Section 3.1.1.1).

Figure 3-13 shows tests at 125°C and 60% KOH.

Test TLT-2-410 was started with a ceria-PTFE matrix in a round cell at 100 ma/cm<sup>2</sup>. The initial and maximum voltage was 1.013 v. During 82 hours the overall voltage decline rate (23 mv/100 hours) was high. The cell then developed a cross-leakage of gas and the run was terminated. Inspection of the cell showed breaks in the matrix along the edges of the electrodes. This was caused by the matrix dropping unsupported into the cavity along a 1/8" periphery around the electrodes.

The cell was re-assembled with fresh electrodes and matrix. To prevent matrix breakage the peripheral space in the cavity was filled with PTFE shim. The test (TLT-2-411) was run at 100 ma/cm<sup>2</sup>. While the KOH within the cell was concentrating from 50% to 60% the initial voltage climbed to 1.048 v and then fell to 1.037 v within eight hours. The test then ran stably at 1.03 v for 300 hours. The voltage decline rate was 1.7 mv/100 hours.

All pressure tests at 45 psig were terminated by an inadvertent drop in the hydrogen line pressure to 30 psig. This is discussed further in Section 4.4. The pressure test stations were re-designed to provide greater safety. The re-design is described in detail in Section 4.5.



TABLE 3-1

## Small Cell Life Tests: Atmospheric Pressure (a)

Cell: Two Inch  
Electrodes: AB-40

TLT No.	Matrix	Dry Thickness (Mils)	Current Density (ma/cm <sup>2</sup> )	KOH Conc. (%)	KOH Loading g/g cc/cm <sup>2</sup> Matrix	Inlet Gas Condition	Inlet Gas Flow Rates [cc/min. at 0 psig and 23°C]		Inlet Gas Flow Ratio (H <sub>2</sub> /O <sub>2</sub> )	Test Duration (Hours)	Working Voltage (v)			Overall Voltage Decline Rate (mv/100 hrs)	Cell Resistance (Milliohms)			Status	Reason For Termination
							H <sub>2</sub>	O <sub>2</sub>			Initial	Maximum	Now or Final		Initial	Minimum	Now or Final		
Tests at 100°C																			
2-322	ACCO-I Asbestos	25	100	50	3.1	.68	Humidified at 45°C	74	74	1.0	3690	.944	.865	1.7	4.2	3.4	4.1	Continuing Terminated	(1)(2)
2-356	"	20	"	"	"	"	"	"	"	"	688	.938	.860	2.0(b)	4.0	2.8	3.0		
2-357	"	20	"	"	"	"	"	"	"	"	2153	.943	.929	0.8	3.0	2.8	2.8	Continuing	-
2-324	Fuel Cell Asbestos	22	"	"	1.3	.70	"	"	"	"	3689	.915	.902	1.0	7.1	5.8	6.2	"	-
2-358	"	21	"	"	1.6	.86	"	"	"	"	1200	.917	.916	0	7.0	5.3	6.6	Current Density Raised to 200 ma/cm <sup>2</sup>	-
2-359	"	20	"	"	1.5	.81	"	"	"	"	1200	.936	.908	2.3	7.1	5.5	7.2	"	-
2-354	Quinterra Asbestos	23	"	"	3.2	1.30	Dry	48	48	"	1707	.936	.893	1.8	7.1	5.5	7.1	"	-
2-360	Ceria-PTFE	37	"	"	0.58	.86	Humidified at 55°C	115	115	"	1440	.928	.938	0	5.3	3.3	3.6	"	-
2-407	"	24	"	"	0.62	.91	"	"	"	"	331	.927	.918	2.7	5.9	5.8	6.0	Temp. Raised to 125°C	-
2-358(c)	Fuel Cell Asbestos	21	200(c)	50	1.6	.86	Humidified at 45°C	148	148	"	940	.938	.932	0.6	4.1	4.0	4.3	Temp. Raised to 125°C	-
2-359(c)	"	20	"(c)	"	1.5	.81	Humidified at 55°C	230	230	"	459(c)	.852	.821	6.9	6.2	5.7	5.7	Current Density Raised to 200 ma/cm <sup>2</sup>	-
2-406	"	22	"	"	"	"	"	230	230	"	326(c)	.842	.762	25	6.4	5.6	5.6	Continuing	-
2-354(c)	Quinterra Asbestos	23	"(c)	"	3.2	1.30	Dry	96	96	"	1434	.879	.770	8.7	6.0	4.6	6.5	"	-
2-335	ACCO-I Asbestos	21	300	50	3.3	.72	Dry	144	144	1.0	1200(c)	.877	.882	0.8	3.4	3.0	3.9	"	-
2-401	"	22	"	"	3.4	.75	"	"	"	"	3195	.878	.846	Accelerating	3.9	3.0	4.0	Terminated	(2)
2-402	"	22	"	"	3.2	.70	"	"	"	"	117	.849	.811	32	3.0	3.0	3.0	"	(3)
2-403	"	22	"	"	"	"	"	"	"	"	161	.862	.862	20	3.2	3.0	3.0	"	(3)
2-404	"	22	"	"	"	"	"	"	"	"	1200	.879	.813	5.5	3.1	2.8	3.4	"	(3)
2-404	"	21	"	"	"	"	"	"	"	"	1726	.879	.899	7.0	3.1	2.8	3.5	"	(3)
2-405	"	22	"	"	"	"	"	"	"	"	1200	.863	.853	0.8	2.8	2.8	2.9	"	(4)
2-404	"	21	"	"	"	"	"	"	"	"	1632	.863	.863	2.0	2.8	2.8	3.1	"	(4)
2-405	"	22	"	"	"	"	"	"	"	"	1200	.878	.878	3.2	2.9	3.1	3.0	Continuing	-
2-405	"	22	"	"	"	"	"	"	"	"	1605	.878	.816	3.9	2.9	2.8	3.0	"	-
2-355(d)	"	20	"	"	3.1	.68	H <sub>2</sub> Humidified at 55°C	615	30+(e)	20	1000	.863	.884	4.6(f)	4.4	3.4	3.1	Terminated	(2)
Tests at 125°C																			
2-360(c)	Ceria-PTFE	37	100	60	0.58	.86	Humidified at 55°C	167	167	1.0	1200(c)	.863	.848	1.3	5.9	5.9	6.3	Continuing	-
2-408	"	23	"	"	1.08	1.86	"	"	"	"	1169	.974	.925	4.0	3.2	3.2	8.3	"	-
2-409(c)	"	24	200(c)	"	0.62	.91	"	"	"	"	325(c)	.936	.941	2.8	4.0	4.0	4.2	"	-

## Reasons for Termination

- (a) In all tests electrodes were pre-wet with electrolyte.  
 (b) Prior to accelerated voltage decline starting at 520 hours.  
 (c) Test had run first at 100°C and 100 ma/cm<sup>2</sup> for period shown in Table.  
 (d) Matrix contains 20% binder instead of the usual 10%.  
 (e) + indicates less than 5 cc/min. excess over indicated stoichiometric flow rate.  
 (f) Prior to abrupt voltage decline at 100 hours.
- (1) Electrolyte loss from cell.  
 (2) Accelerated voltage decline - caused by gas cross-leakage.  
 (3) Rapid voltage decline.  
 (4) Rapid voltage decline after 1200 hours.

TABLE 3-2  
Small Cell Pressure Life Tests

TLF No.	Matrix	Thickness (Mils)	Temp. (°C)	Current Density (ma/cm <sup>2</sup> )	KOH Conc. (%)	KOH Pressure (psig)	KOH Loading g/g Matrix	Inlet Gas Condition	Inlet Gas Flow Rates [cc/min. at 0 psig and 23°C]		Inlet Gas Flow Ratio (H <sub>2</sub> /O <sub>2</sub> )	Test Duration (Hours)	Working Voltage (v)		Overall Voltage Decline Rate mv/100 Hours	Cell Resistance (Milliohms)			Status	Reason For Termination
									H <sub>2</sub>	O <sub>2</sub>			Initial	Maximum		Initial	Minimum	Final		
2-412	Fuel Cell	22	100	100	50	45	1.5	H <sub>2</sub> Humidified at 550C;	940	10+(a)	94	72	.987	.987	70	9.1	7.0	7.0	Terminated	(1)
2-413	Asbestos	20	"	200	"	"	"	O <sub>2</sub> Dry	1880	20+(a)	"	49	.961	.961	150	4.5	4.5	4.5	"	(1)
2-340	"	20	"	"	50 or 46	15	1.3	Dry	243	123	2.0	1440	.925	.925	6.0	6.5	4.6	6.4	"	(2)
2-409	Quinterra	22	"	"	"	"	"	Humidified at 550C	970	970	1.0	580	.959	.959	3.5	6.7	6.7	8.2	"	(3)
2-410	Asbestos	27	125	100	60	"	3.1	"	670	670	"	82	.936	.936	23(b)	4.4	4.4	8.8(b)	"	(4)
2-411	Ceria-PtFE	27	"	"	"	"	0.48	"	"	"	"	300	1.013	1.013	1.7	5.0	5.0	5.3	"	(3)

(a) + indicates less than 5 cc/min. excess over indicated stoichiometric flow rate.  
(b) Prior to abrupt voltage decline at 82 hours.

Reasons for Termination

- (1) Rapid voltage decline.
- (2) Modification of test facilities required removal of cell.
- (3) Loss of hydrogen line pressure.
- (4) Abrupt voltage decline - caused by gas cross-leakage.

TABLE 3-3

KOH Concentration Gradient and Voltage Stability

Pressure: 0 psig

TLT No.	Matrix	Temp. (°C)	Current Density (ma/cm²)	Total Elapsed Time (Hours)	Equilibrium KOH Conc. (%) at		KOH Conc. Gradient (%)	Voltage Decline Rate During Period of Concentration Measurements (mv/100 Hours)	Voltage Stability During Period of Concentration Measurements Period
					H <sub>2</sub> Exit	O <sub>2</sub> Exit			
2-322	ACCO-I Asbestos	100	100	1653	47	51	4.0	(a)	Stable
				2021	50.5	54	3.5		
				2060	46	52	6.0		
				2676	46.5	52.5	6.0	0(a)	Stable
				2921	46.5	52.5	6.0		
				3284	41.5	53.0	11.5		
				3451	46.5	56.0	13.5		
2-356	"	"	"	140	48	49	1.0	1.7	Stable
				377	51.5	55	3.5		
2-357	"	"	"	116	48	51	3.0	0.6	Stable
				453	49.5	51	1.5		
				1142	47.5	51	3.5		
				1381	48	51	3.0		
				1912	50.5	50.	-0.5		
				1947	48.5	50.5	2.0		
2-335	"	"	300	1436	48	50.5	2.5	3.2	Stable
				1749	48.5	50	1.5		
				2393	51.5	50	-1.5		
				2651	56	50	-6.0		
				2812	52	47.5	-4.5		
2-401	"	"	"	91	44.5	54	9.5	32	Unstable
2-402	"	"	"	90	43.5	55	11.5	24	Unstable
2-403	"	"	"	45	46.5	54	7.5	7.0	Unstable
				639	48.5	53.5	5.0		
				901	46.0	53.	7.0		
				1057	45.5	52.5	7.0		
				1289	46.0	53.5	7.5		
				1440	46.5	53.	6.5		
				1467	46.5	50.5	4.0		
				1696	50.5	48.7	-1.8		
2-404	"	"	"	138	42.5	58	15.5	40 (0-100 Hours) Voltage Rising (100-138 Hours)	Unstable
2-405	"	"	"	117	43.5	56	12.5	25	Unstable <sup>(a)</sup>
				543	50.5	56	5.5		
				811	47	54	7.0		
				1349	48	52	4.0		
				1605	48.5	51.5	3.0		
2-324	Fuel Cell Asbestos	"	100	1650	47.5	50	2.5	0.9	Stable
				2058	46.5	51.5	5.0		
				2674	48	50.5	2.5		
				2920	48	50	2.0		
				3480	48.5	49.0	0.5		
2-358	"	"	"	91	47.5	49	1.5	0	Stable
				137	47.5	51	3.5		
				427	48.5	50	1.5		
				1113	48.5	50.5	2.0		
				1358	48.5	50	1.5		
2-358	"	"	200	53	48	49.5	1.5	6.6	Unstable
				227	47	49.5	2.5		
				353	49	49.5	0.5		
2-359	"	"	100	19	47	51	4.0	1.6	Stable
				403	47.5	51	3.5		
				1043	47	52	5.0		
				1064	47.5	52.5	5.0		
				1284	47.5	52.5	5.0		
2-359	"	"	200	109	46	53	7.0	30	Unstable
				114	47	54	7.0		
				158	47.5	54	6.5		
2-406	"	"	200	443	46.5	51.5	5.0	0	Stable
				466	47	52	5.0		
				684	47	51	4.0		
2-354	Quinterra Asbestos	"	100	622	46	51.5	5.5	0	Stable
				936	46.5	52	5.5		
2-354	"	"	200	136	51	53	2.0	0	Stable
				397	48	55	7.0		
				582	45.5	53	7.5		
				942	46	52	6.0		
				1198	46	53	7.0		
2-360	Ceria-PTFE	"	100	215	47	52	5.0	0	Stable
2-360	"	125	"	305	57.5	61.5	4.0	0	Stable
				537	58	61.5	3.5		
				561	57.5	60.5	4.0		
				788	57.5	60	2.5		
2-408	"	"	"	173	57.5	62	4.5	2.6	Stable
				202	58	61	3.0		
				440	59	61	2.0		
				952	58	60.5	2.5		
				1063	56	58.5	2.5		

(a) During period indicated in brackets.

# SMALL CELL LIFE TESTS AT ATMOSPHERIC PRESSURE: 100 °C: 100 ma/cm<sup>2</sup>: <2000 HRS.

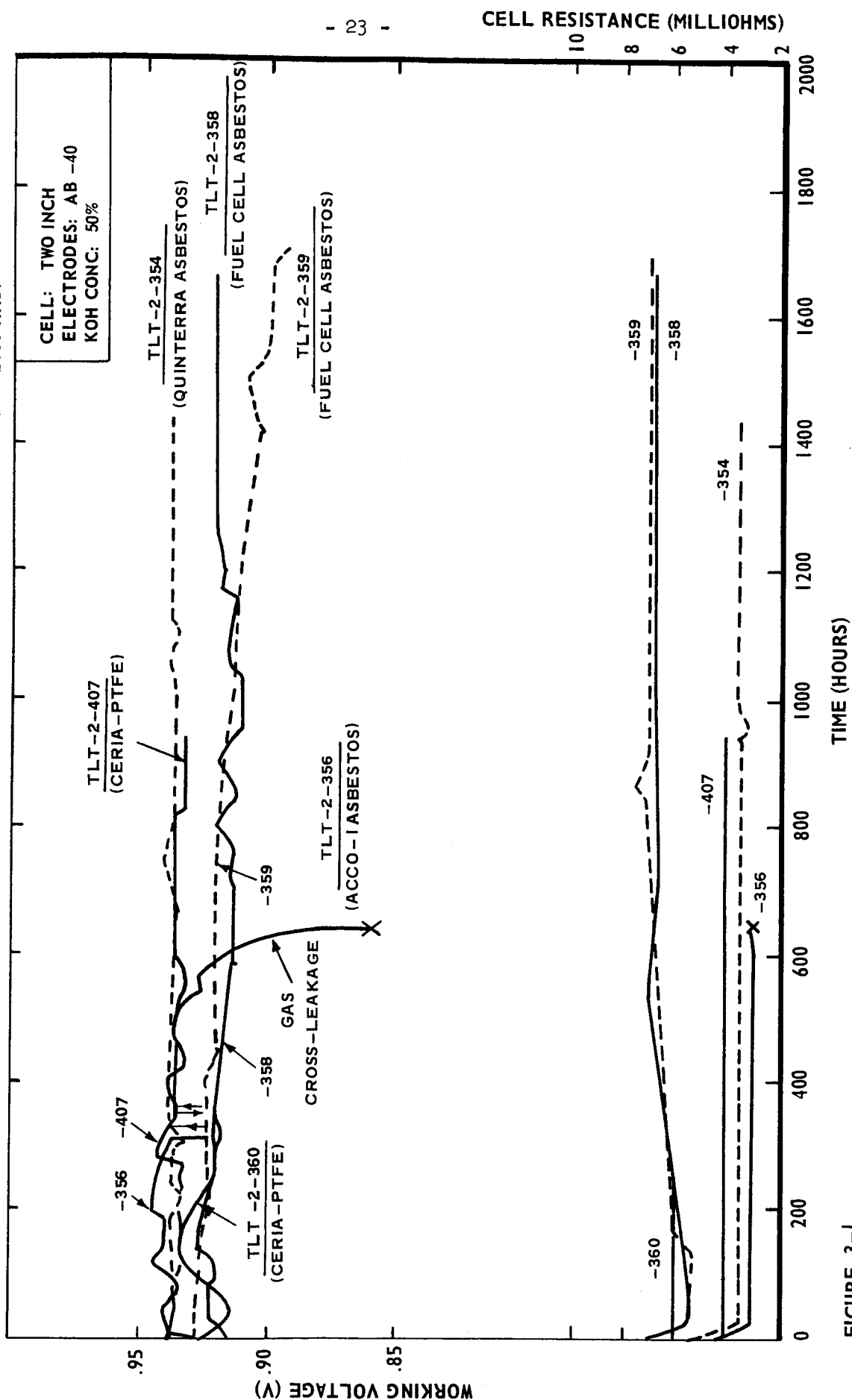


FIGURE 3-1

# SMALL CELL LIFE TESTS AT ATMOSPHERIC PRESSURE: 100 °C; 100 ma/cm<sup>2</sup> ; > 2000 HRS.

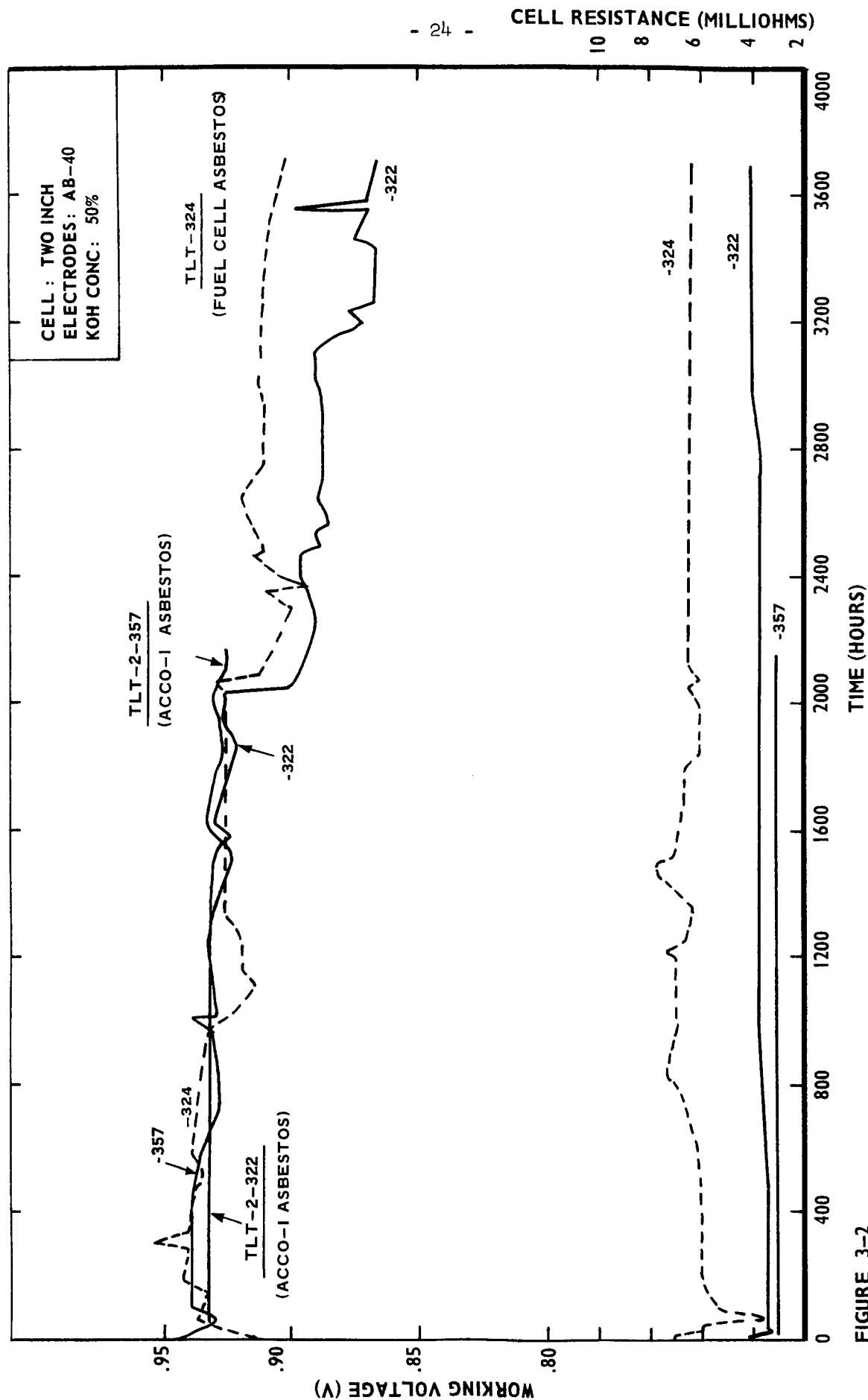


FIGURE 3-2

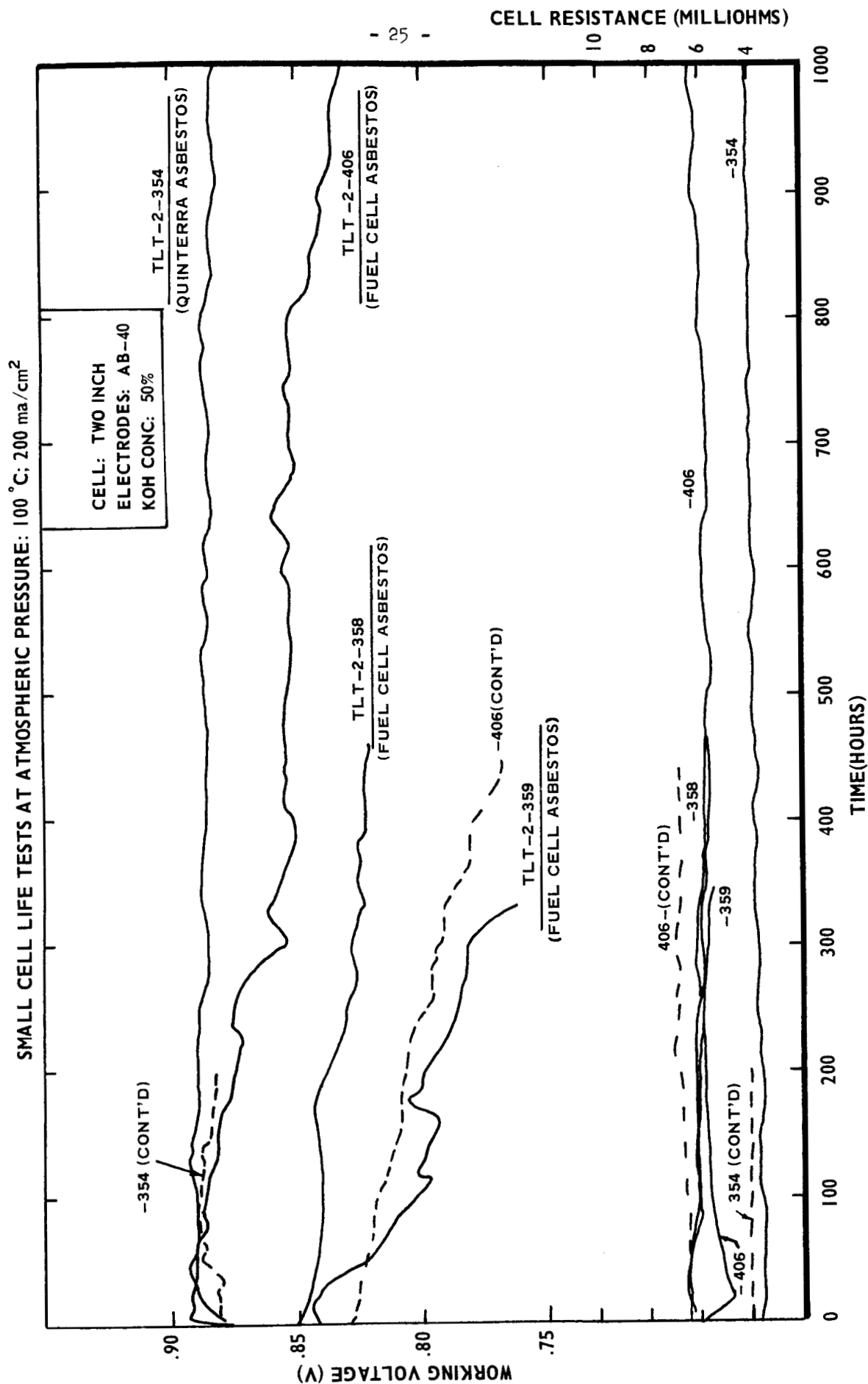


FIGURE 3-3

# SMALL CELL LIFE TESTS AT

ATMOSPHERIC PRESSURE 100 °C: 300 ma/cm<sup>2</sup> : < 2000 HRS.

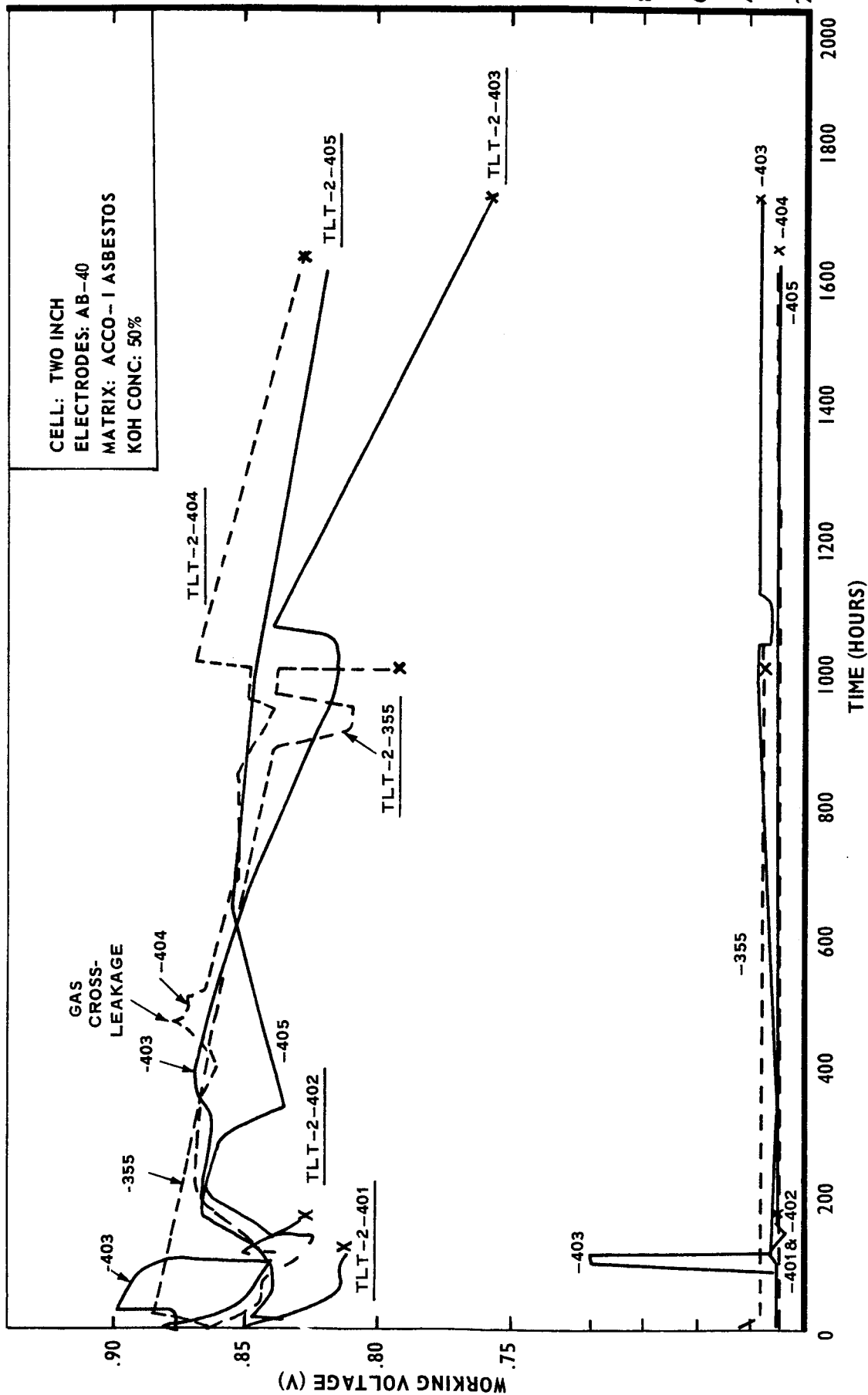


FIGURE 3-4

SMALL CELL LIFE TEST AT  
ATMOSPHERIC PRESSURE: 100°C: 300 ma/cm<sup>2</sup> : > 2000 HRS.

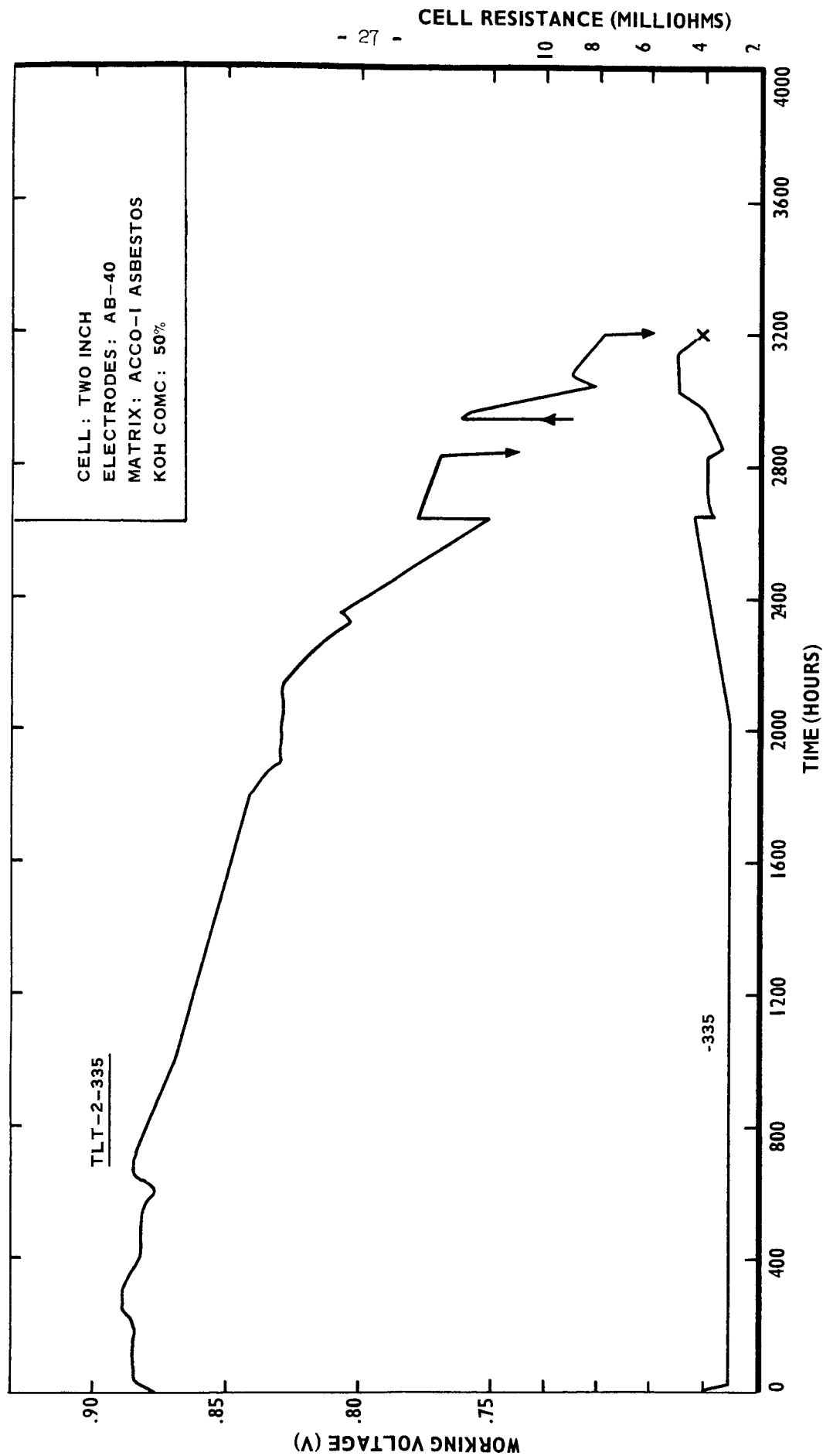


FIGURE 3-5



SMALL CELL LIFE TESTS AT  
ATMOSPHERIC PRESSURE: 125 °C

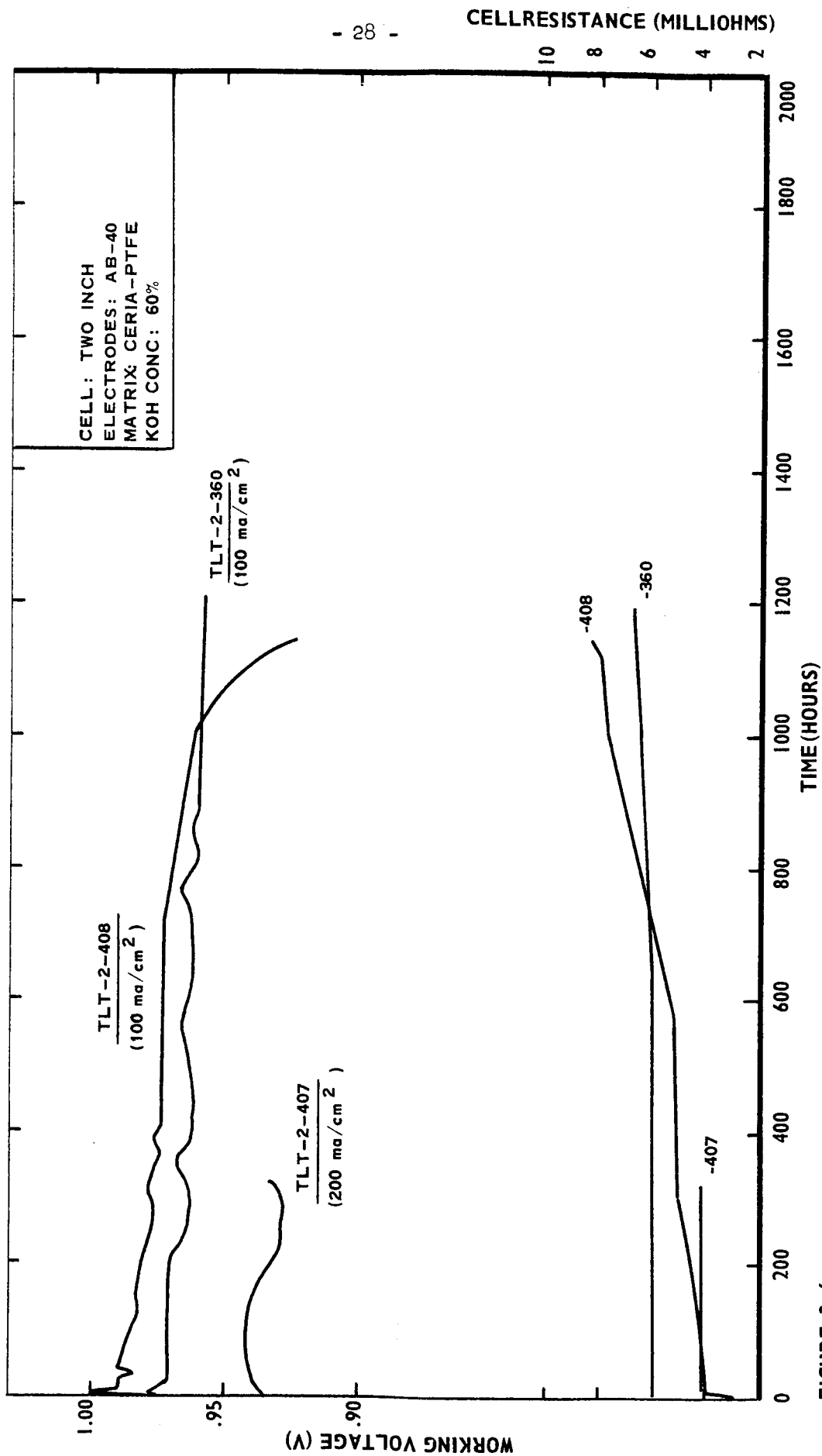


FIGURE 3-6

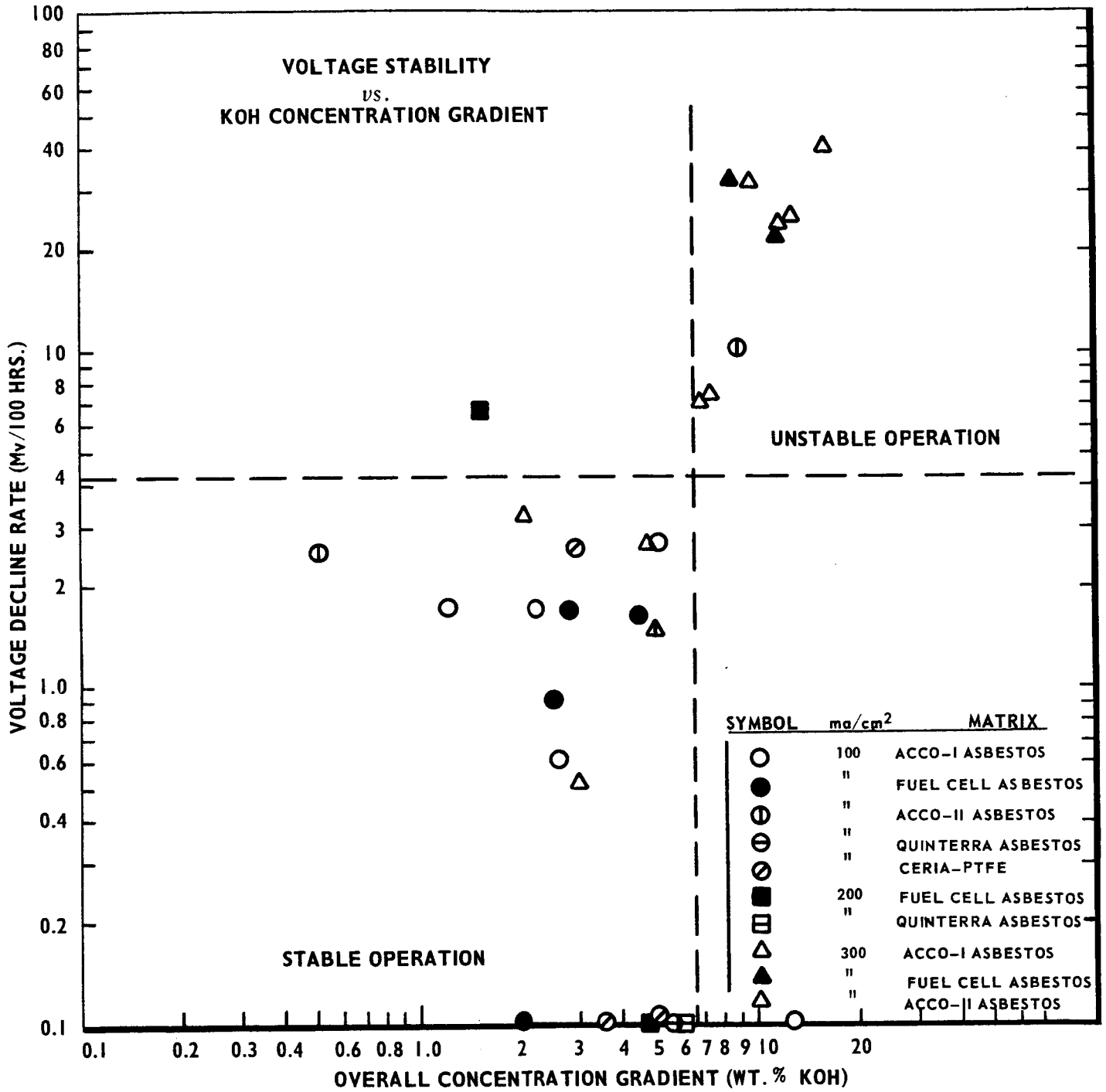
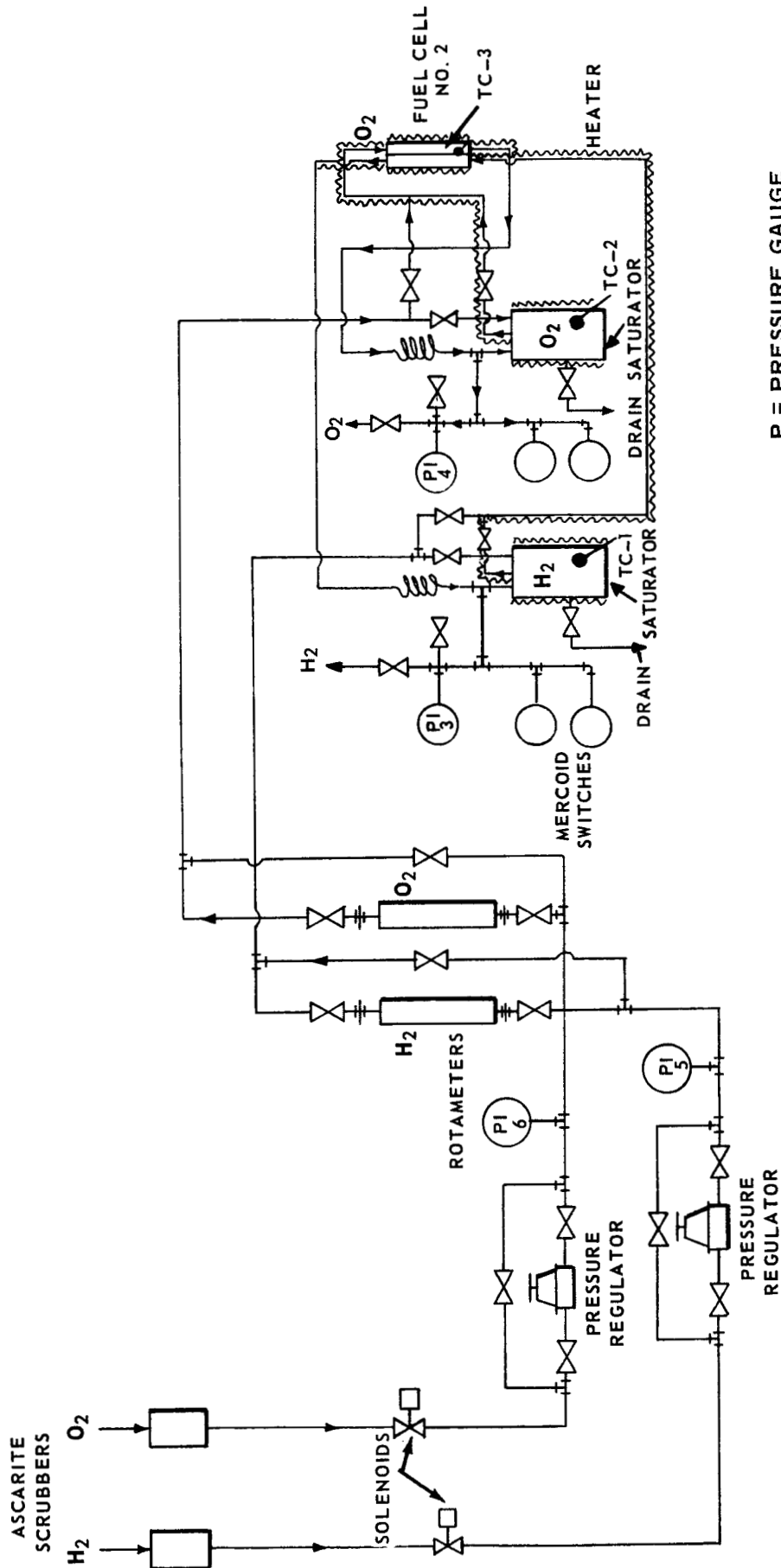


FIGURE 3-7

# SMALL CELL PRESSURE LIFE TEST STATION



P = PRESSURE GAUGE  
TC = THERMOCOUPLE

FIGURE 3-8

Figure 3-9 - Two Inch Square Pressure Cell

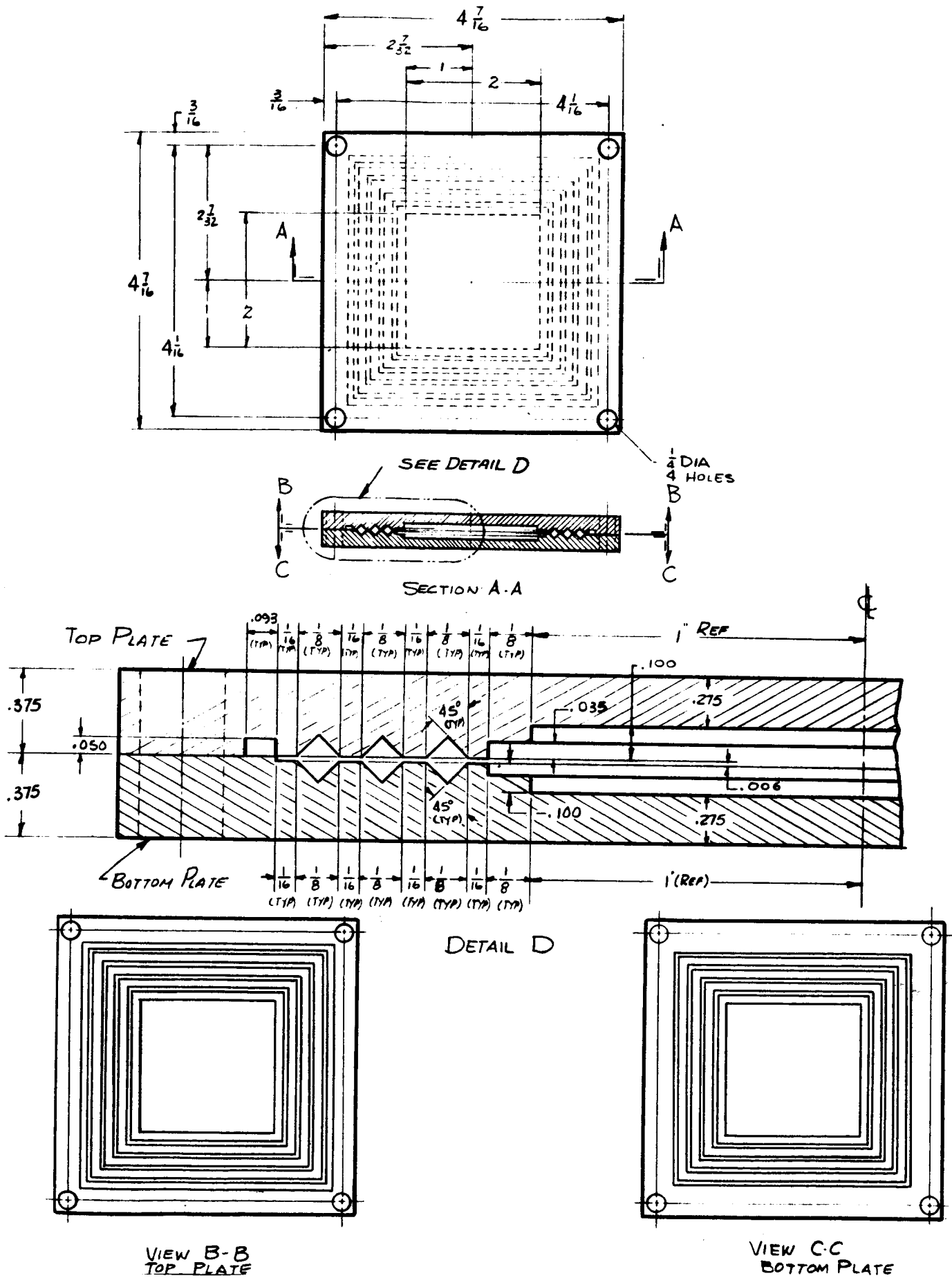
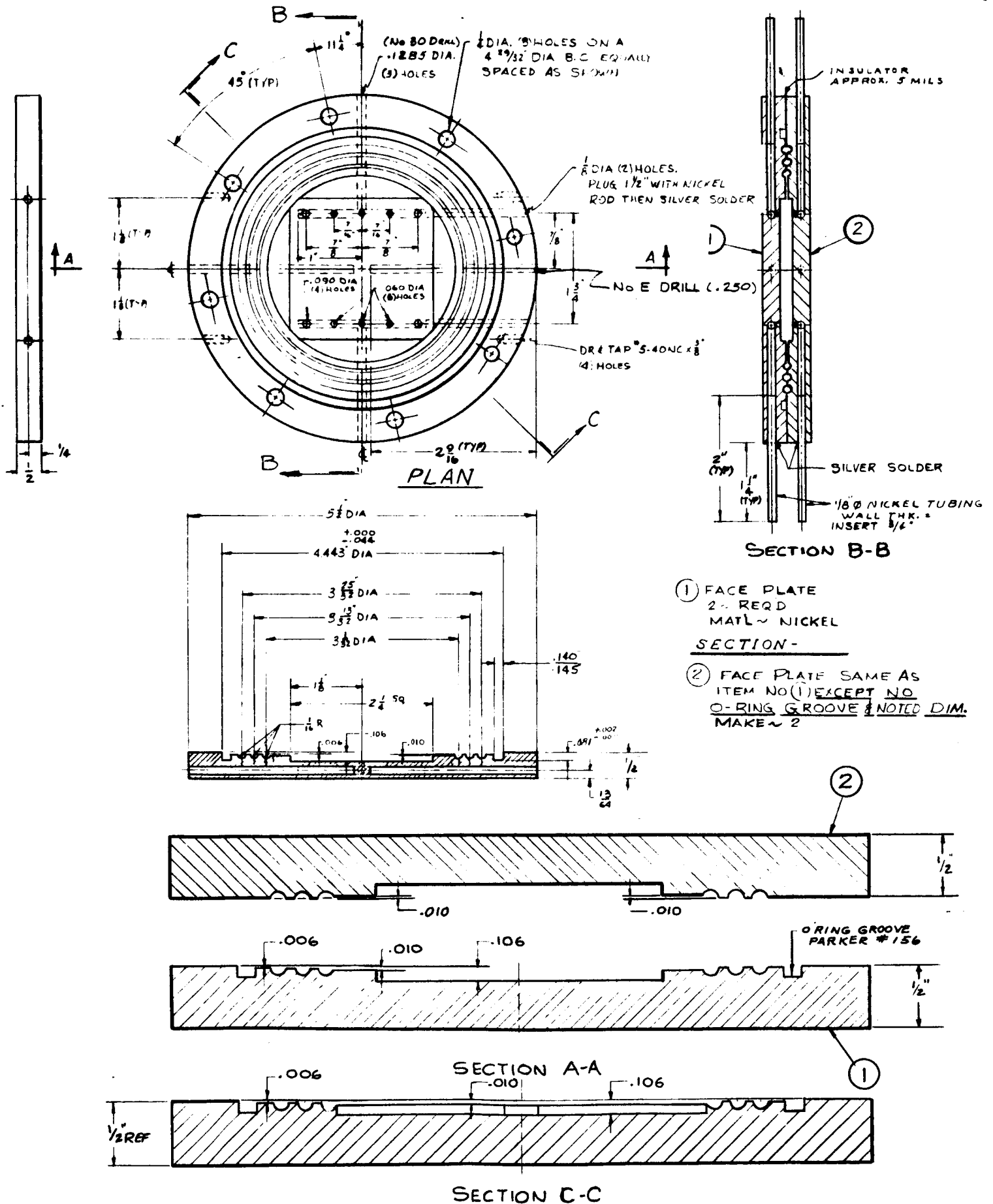


Figure 3-10 - Two Inch Round Pressure Cell



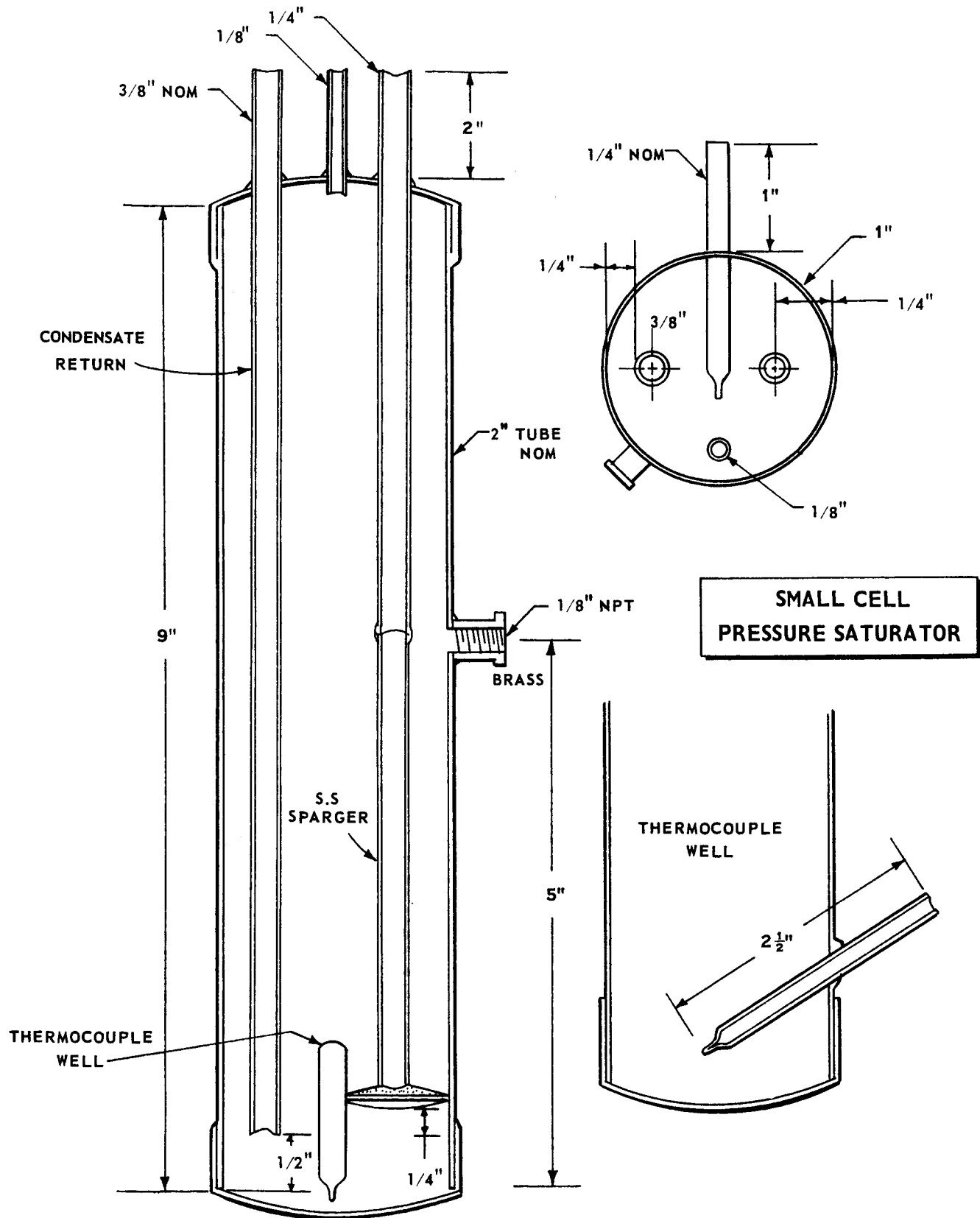


FIGURE 3-11

# SMALL CELL PRESSURE LIFE TESTS: 100 °C

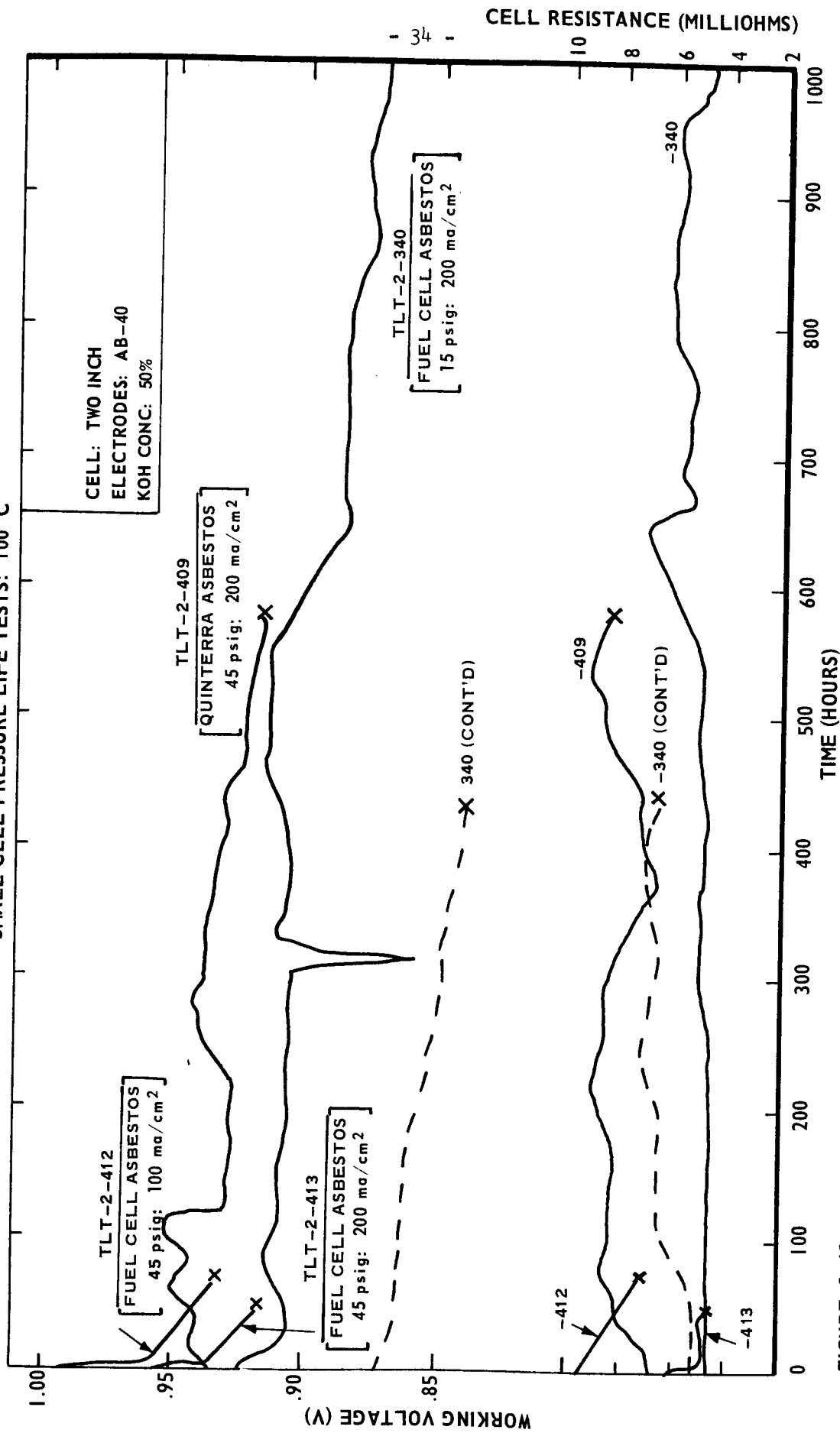


FIGURE 3-12

# SMALL CELL PRESSURE LIFE TESTS: 125 °C.

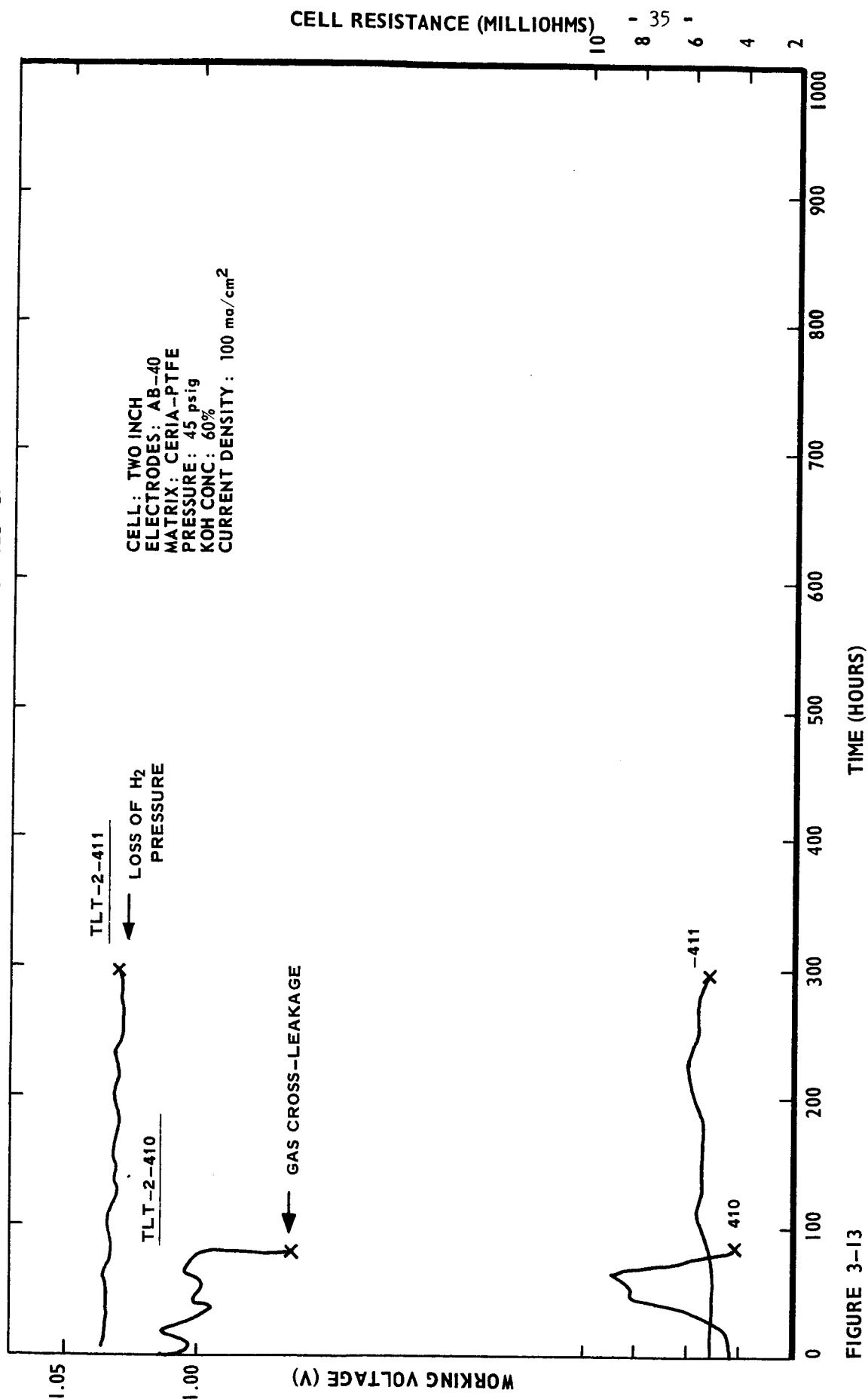


FIGURE 3-13



#### 4. LARGE CELL TESTING

Large cell life tests were run in 6-inch cells (6 inch square electrodes) at atmospheric pressure and at 45 psig. Three pressure cells and their test stations were constructed for this purpose. A separate test rig was constructed for running matrix failure tests prior to life testing.

##### 4.1 Matrix Failure Tests

During life testing, an explosive mixture of hydrogen and oxygen within the cell might be produced by cross-leakage of gas through the matrix. Cross-leakage could result from imperfections in the matrix, matrix corrosion, or from a pressure differential across the cell caused by a pressure control failure. Preliminary to large cell life testing, a study was made to determine what differential pressure causes reactant gas leakage through Fuel Cell Asbestos and ACCO-I Asbestos matrices under typical operating conditions and to determine whether cross-leakage produces a fire or an explosion.

The failure test cell was essentially a steel replica of the gasketed flat plate six inch cells used previously for large cell testing<sup>(3)</sup>. The only design difference in the failure test cell was that it had a single inlet and exit port for each gas instead of the usual manifold system.

The test rig is shown in Figures 4-1. The rig was built behind a steel barricade with an observation port. The hydrogen and oxygen supplies were located behind a separate barricade. Each gas was metered

before entering the cell. A water saturator protected by a check valve was installed in the hydrogen line. Pressure regulators, quick shut off valves, and cell exit valves were controlled manually from behind the barricade.

The failure tests were conducted under typical life test conditions. Each run was started at 100°C, 50% KOH and 45-48 psig on each side of the cell. The inlet hydrogen stream was humidified at 55°C while the inlet oxygen stream was dry. A high current density (300 ma/cm<sup>2</sup>) was chosen so that testing would be at high flow rates of an explosive mixture of hydrogen (14,000 cc/min) and oxygen (1,200 cc/min). With the gases flowing and the cell producing power, the tests were carried out by either lowering or raising one of the gas pressures in increments of 3-5 psig for 1-2 minutes until cross-leakage occurred.

In three tests with 20 mil Fuel Cell Asbestos matrices a pressure differential of 20-45 psig caused cross-leakage, as evidenced by a rise in cell temperature. Despite cross-leakage the differential pressure was maintained at 35-45 psig for 3-7 minutes and at 5-30 psig for 25 minutes. In a fourth test cross-leakage occurred at 45 psig with no pressure differential, because of faulty cell assembly. In all tests cross-leakage was accompanied by burning which raised the cell temperature to as high as 258°C in 20 minutes. (The runs were terminated before higher temperatures were reached.) Intermittent jets of flame were visible through a PTFE connector placed 3-4 inches downstream from the

hydrogen exit port. In two runs the connector burst and a flame jet, 2-4 inches long was emitted through the tube for a few seconds before the gases were shut off. No explosion occurred in any of these tests.

In one test with 20 mil ACCO-I Asbestos a pressure differential of only 3 psig caused cross-leakage and equalization of the pressures within one minute. This indicates the considerable difficulty that would be encountered in using the ACCO-I Asbestos matrix for pressure life tests. Within 25 minutes, the cell temperature rose to 180°C and intermittent flame jets were visible. There was no explosion.

#### 4.2 Pressure Test Stations

A typical large cell pressure life test station is shown schematically in Figure 4-3. The station is essentially the same as the small cell station (Figure 3-8) except that there is no saturator in the oxygen line.

The design of the 6-inch pressure cell has been described previously<sup>(3)</sup> and is essentially the same as that of the small round pressure cell (Figure 3-10). The face plates are 11½ inches x 11½ inches x 3/8 inches thick. The cavity for each electrode is 6 inches x 6 inches x 0.055 inch deep. Each plate has four lands and three grooves.

Figure 4-3 shows the saturator design. Two of the saturators were 12 inches diameter x 30 inches high. The third was 18 inches diameter x 30 inches high. The tank is of stainless steel with a removable carbon steel flange at the top. The sparger is made of porous stainless steel. The water level was maintained at 16-20 inches above the sparger

by occasional pumping from a separate tank. The water temperature was maintained constant at 55°C by heating tape regulated by an on-off controller. Agitation provided by even the lowest gas rate used in the life tests (3500 cc/min) was sufficient to maintain a uniform temperature throughout the liquid. Condensation from the gas leaving the liquid was prevented by separately heating the vapor space and the top flange to 58-60°C and 60-70°C respectively. The line from the saturator to the cell was heated to 70-100°C. The porous PTFE separator prevented liquid from splashing into the hotter vapor zone. Tests showed that over the range of flow rates employed in the life tests (3500-5000 cc/min), the hydrogen stream left the saturator completely saturated. The maximum pressure drop through the saturator at these flow rates was 2 psig.

#### 4.3 Test Results

##### 4.3.1 Atmospheric Pressure Life Test

Test 7676-84 was run at 100°C, 50% KOH, and 0 psig at 300 ma/cm<sup>2</sup>. The matrix was 20 mil ACCO-I Asbestos. The electrodes were pre-wet to 20% of their weight with electrolyte and the KOH loading in the matrix was 3.5 g/g dry matrix. Essentially all of the product water was removed by 3500 cc/min of hydrogen humidified at 55°C. Oxygen entered the cell dry at 300 cc/min.

Test conditions and results are given in Table 4-1 and Figure 4-4. The initial voltage was 0.870 v. During 190 hours the voltage fell to 0.847 v at a high decline rate (12 mv/100 hours). Cross-leakage of gas was encountered and the run was terminated.

#### 4.3.2 Pressure Life Tests

Pressure life test conditions and results are summarized in Table 4-1. All tests were run at 45 psig. The electrodes were pre-wet with 20% of their weight of electrolyte. Essentially all of the product water was removed by hydrogen humidified at 55°C. The inlet oxygen stream was dry. Voltage time curves are shown in Figure 4-4.

Test 7676-92 was run at 100 ma/cm<sup>2</sup> with 20 mil Fuel Cell Asbestos as the matrix. The initial KOH loading was 1.5 g/g matrix. The run was started with a 0 psig differential pressure across the matrix. The initial voltage was 0.970 v. During the first 22 hours the voltage decreased to 0.939 v. At this point it was found that the voltage could be increased to 0.955 v by raising the differential pressure across the matrix on the hydrogen side to 1 psig. (The voltage improvement was not due to the change in total pressure since the differential was created by decreasing the oxygen pressure.) Further increase in the differential pressure on the hydrogen side to 2 psig produced only a slight additional increase in voltage to 0.960 v while a differential pressure of 1 psig on the oxygen side decreased the voltage to 0.937 v. Accordingly the run was continued with a 1 psig differential pressure on the hydrogen side. During the next 168 hours the test ran stably at a voltage decline rate of 3.0 mv/100 hours. The test was terminated at 190 hours when severe cross-leakage of gas developed, (evidenced by a sudden equalization of gas pressure), which decreased the current and voltage to zero.

Test 7676-102 was a repeat of test 7676-92 at 100 ma/cm<sup>2</sup> except that the test was started with a differential pressure of 1 psig on the hydrogen side (total oxygen pressure = 44 psig). The initial voltage

was 0.988 v. During the first 23 hours the voltage loss was 1 mv. The differential pressure was then varied from 0-2 psig on each side of the cell. Unlike the results of test 7676-92, this did not change the voltage by more than + 1 mv. The test was then continued at a differential pressure of 0 psig. During the next 53 hours the voltage declined rapidly to 0.970 v. At 76 hours the temperature control probe in the cell failed, the temperature rose to 145°C for three hours and the voltage fell to 0.68 v. When the cell was cooled to 100°C the voltage did not rise above 0.87 v during the next 40 hours. The test was then terminated.

Test 7676-114 was started with Fuel Cell Asbestos at 100 ma/cm<sup>2</sup> with no differential pressure across the matrix. The initial voltage was 0.994 v. During 290 hours the voltage declined rapidly at 24 mv/100 hours.

Test 7676-120 was started with Quinterra Asbestos at 100 ma/cm<sup>2</sup>. The initial voltage was 0.994 v. During 118 hours the voltage declined rapidly at 24 mv/100 hours.

#### 4.4 Termination of Pressure Tests

Large cell pressure life tests 7676-114 and 7676-120, and small cell tests TLT-2-409, -411, -412, and -413 were terminated simultaneously on a weekend by a decrease in the hydrogen line pressure from 60 to 30 psig. This tripped the low pressure Mercoid switches at each test station and shut off the reactant gas supplies.

#### 4.5 Re-design of Pressure Stations

An attempt to re-start test 7676-120, following the loss of hydrogen pressure caused an explosion in the hydrogen side of the test station when both gases in the cell were at 45 psig. The explosion was apparently caused by cross-leakage of gas through the matrix despite the fact that the maximum differential pressure across the matrix during re-startup was 2 psig. Cross-leakage was probably caused by a substantial momentary pressure differential across the matrix when the gases were automatically shut off. As a result of the explosion the sight glasses, the bottom flange and the sparger were blown out of the saturator tank. The tank itself fell on its side. The cell was not damaged.

Because of the explosion discussed above, both the small cell and large cell pressure stations have been re-designed.

Each station is to be provided with nitrogen lines connected separately through solenoid valves, into the hydrogen and oxygen sides of the system. A solenoid valve in a branch of each line leaving the cell will permit rapid release of gas pressure, if required. During startup the hydrogen side of the system will be purged first with nitrogen. In the event of an emergency, a manual switch will be provided for simultaneously releasing the reactant gas pressure, shutting off the reactant gases (to the particular station) purging nitrogen through both sides of the system, and shutting off power to the cell heater. The same sequence will be triggered automatically by a 5 psig rise or fall of either reactant gas pressure or by a 10°C rise in cell temperature.

In the small cell pressure stations the saturators are to be made of stainless steel, able to withstand a pressure of at least 2000 psig. A pair of check valves in series, set to close at a differential pressure of  $1/3$  psig, is to be installed at each saturator inlet. This should prevent mixing of reactant gases within either feed line which might be caused by cross-leakage through the cell matrix. Since cross-leakage might also form an explosive mixture within the saturator vapor space, added safety could be achieved by locating the check valves at the saturator exits. However, the resulting pressure drop would force water out of the saturator and up through the condensate return line. In order to minimize the magnitude of an explosion within the saturator vapor space, the small volume of this space (200 cc) will be reduced still further to 100 cc by packing with glass beads.

In the large cell pressure stations the saturators with their large vapor volumes (1000 cc) are to be eliminated. One station will be constructed for operation on dry gases only. In a second station each reactant gas is to be humidified in a stainless steel vaporizer having a volume of 70 cc. Each vaporizer will be fed with a constant flow of water from a separate tank pressurized with nitrogen. A pair of check valves in series will be installed at the exit from each vaporizer. A shutdown of the system, either manual or automatic as described above, will also shut off both water streams. In addition, shutdown will occur if the vaporizer heater fails or if the vaporizer temperature, normally 100-150°C, should fall to 50°C.



Construction of the six re-designed test stations is scheduled to be started the first week of April and to be completed by the first week of May.

TABLE 4-1  
Large Cell Life Tests

Cell: Six Inch  
Electrodes: AB-40  
KOH Conc.: 50%  
H<sub>2</sub> Humidified at 55°C: O<sub>2</sub> Dry

T/LT No.	Matrix	Thickness (Mils)	Current Density (ma/cm <sup>2</sup> )	Pressure (psig)	KOH Loading g/g Matrix	Gas Inlet Flow Rates		Test Duration (Hours)	Working Voltage (v)			Overall Voltage Decline Rate (mv/100 Hrs.)	Cell Resistance (Milliohms)			Status	Reason For Termination	
						cc/min at 0 psig and 25°C	H <sub>2</sub> O <sub>2</sub>		Initial	Maximum	Final		Initial	Minimum	Final			
7676-84	ACCO-I Asbestos	20	300	0	3.5	.77	3500	300	11.8	.871	.875	.847	12	.67	.67	.75	Terminated	(1)
7676-92	Fuel Cell Asbestos	"	100	45	1.5	.81	5000	110	45	.970	.970	.948(a)	11(a)	1.3	1.3	1.5	"	(1)
7676-102	"	"	"	"	"	"	"	"	"	.988	.989	.970(b)	15	1.0	1.0	1.0	"	(2)
7676-114	"	"	"	"	1.3	.70	"	"	"	.994	.994	.919	24	1.0	1.0	2.0	"	(3)
7676-120	Quinterra Asbestos	"	"	"	2.9	1.18	"	"	"	.991	.994	.963	24	.85	.85	1.5	"	(3)

(a) Prior to abrupt voltage decline.

(b) Prior to temperature control failure at 76 hours.

Reasons for Termination

- (1) Gas cross-leakage.
- (2) Low voltage following temperature control failure.
- (3) Loss of hydrogen line pressure.

# MATRIX FAILURE TEST RIG

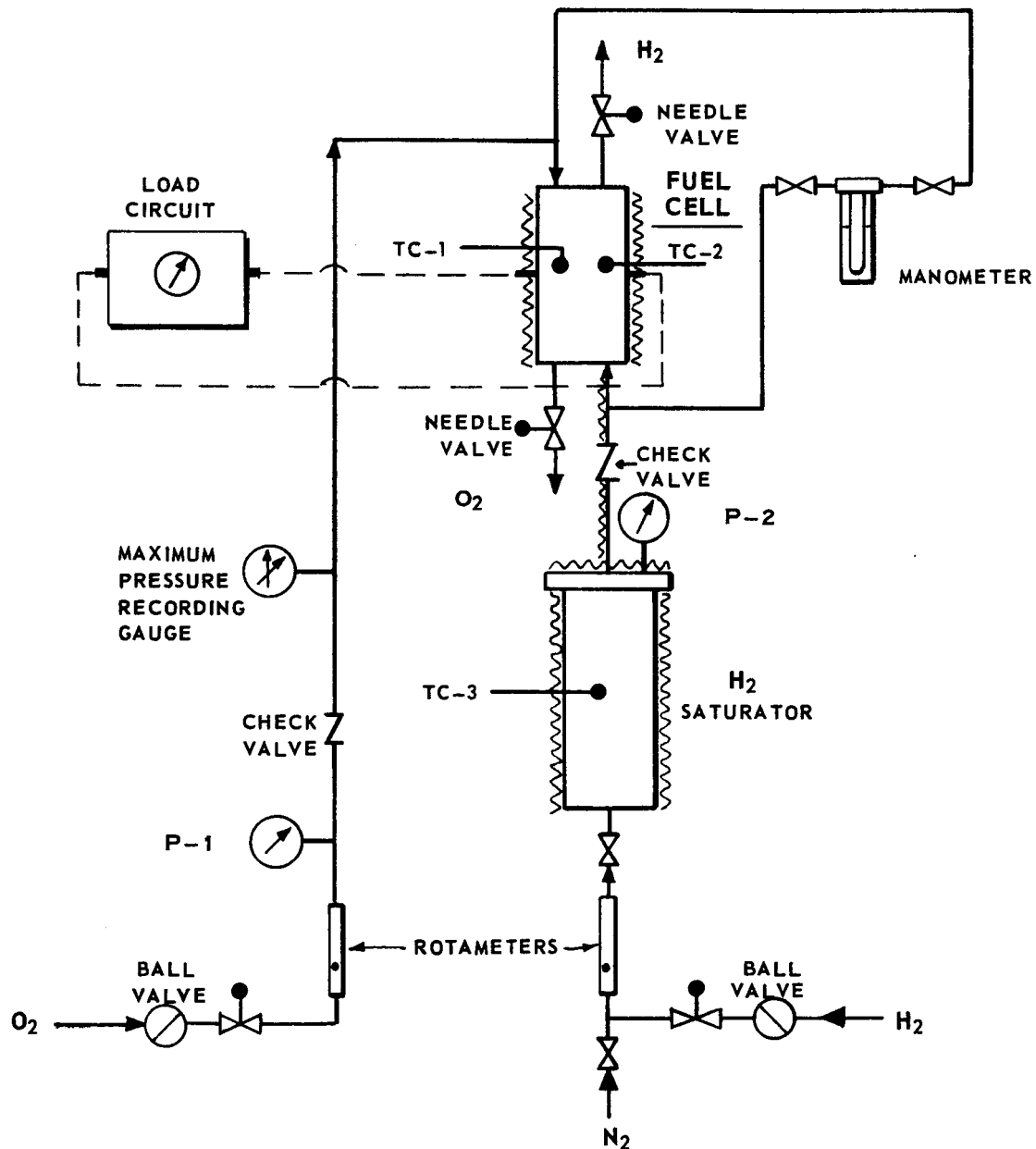


FIGURE 4-1

P = PRESSURE GAUGE  
TC = THERMOCOUPLE

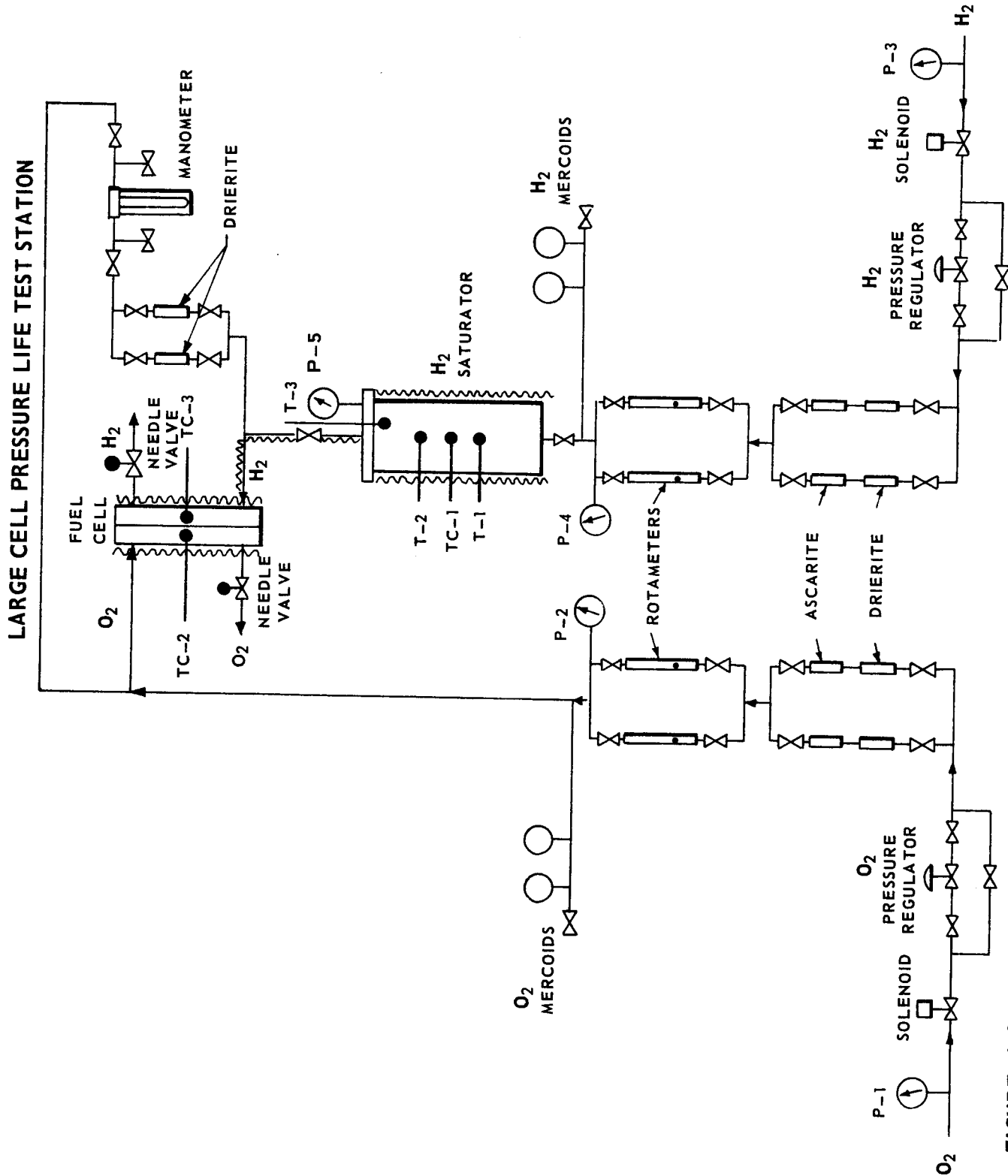


FIGURE 4-2

# LARGE CELL PRESSURE SATURATOR

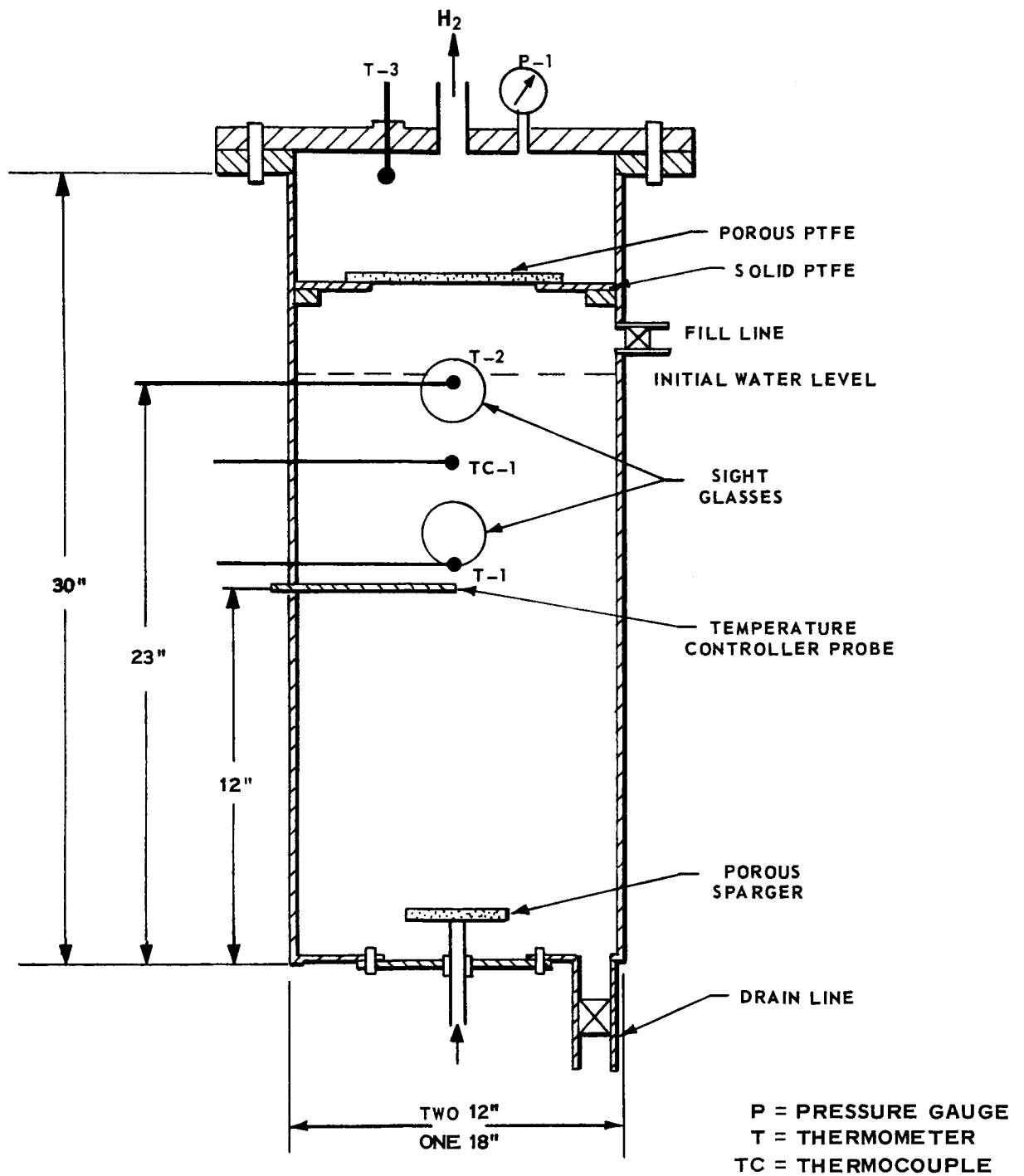


FIGURE 4-3

# LARGE CELL LIFE TESTS:

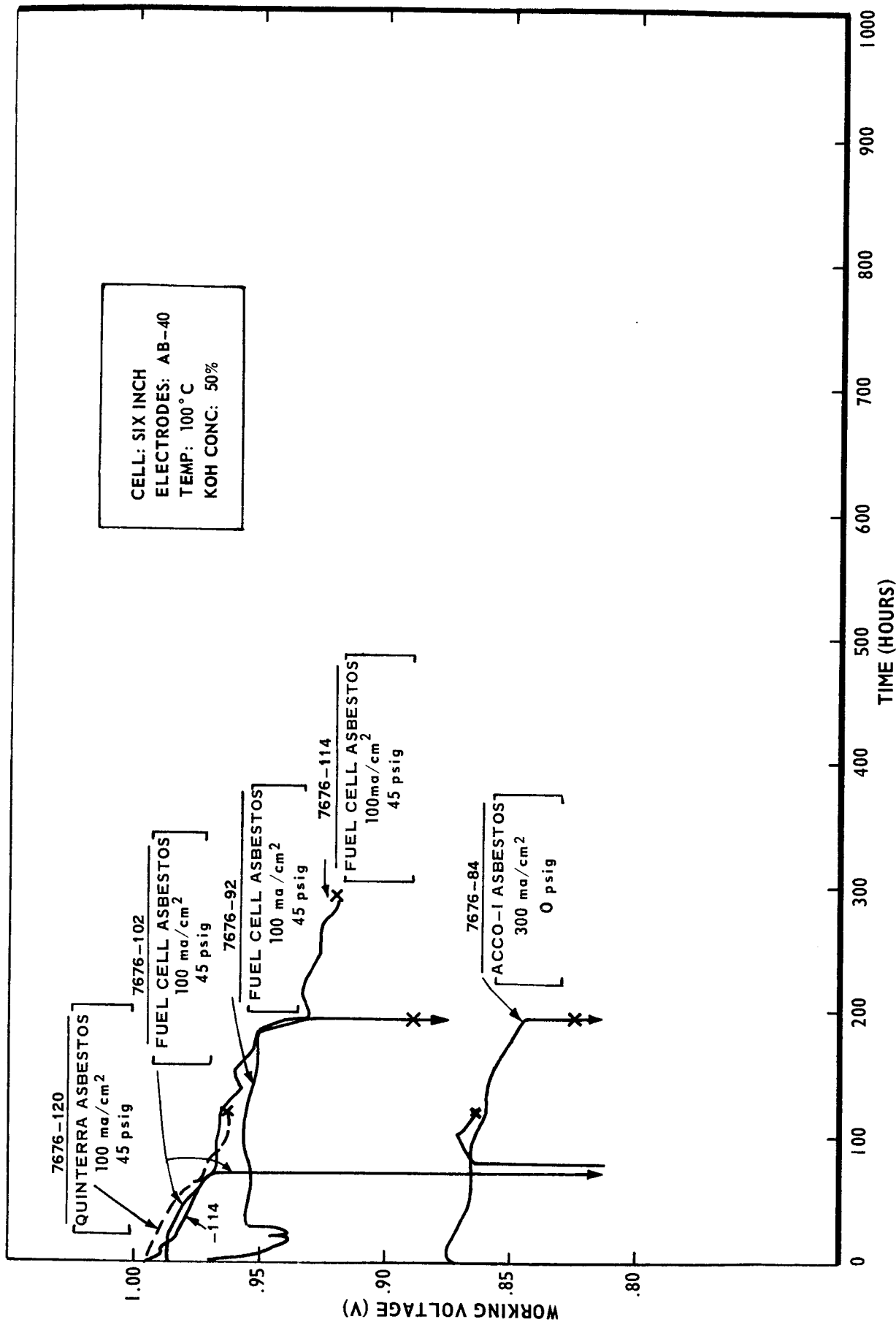


FIGURE 4-4

## 5. FUTURE WORK

Work for the next quarter is planned for the following tasks:

### Small Cell Testing

Life tests at atmospheric pressure which are running stably will be continued beyond 1200 hours. Additional life tests will be started at relatively high temperatures or current densities. This will include tests with Quinterra Asbestos matrices at 100°C, 50% KOH and 200-400 ma/cm<sup>2</sup> and with ceria-PTFE matrices at 125-150°C, 60-67% KOH and 100-300 ma/cm<sup>2</sup>.

Following the construction of four re-designed pressure test stations, life tests will be run at 45 psig with both gases humidified. Runs will be made with Quinterra Asbestos matrices at 100°C, 50% KOH and 100-200 ma/cm<sup>2</sup> and with ceria-PTFE matrices at 125°C, 60% KOH and 100-200 ma/cm<sup>2</sup>.

### Large Cell Testing

Following the construction of two re-designed pressure test stations, life tests will be run with Quinterra Asbestos matrices at 100°C, 50% KOH, 45 psig and 100-200 ma/cm<sup>2</sup>.

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